THE ABUNDANCE AND DIVERSITY OF SMALL MAMMALS AND BIRDS IN MATURE CROPS OF THE PERENNIAL GRASSES *MISCANTHUS X GIGANTEUS* AND *PHALARIS ARUNDINACEA* GROWN FOR BIOMASS ENERGY

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**THESIS SUBMITTED FOR
THE DEGREE OF
DOCTOR OF PHILOSOPHY,
CARDIFF SCHOOL OF BIOSCIENCES,
CARDIFF UNIVERSITY**

DECLARATIONS & STATEMENTS

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This work has not previously been accepted in substance for any degree and is not concurrently submitted in candidature for any degree.

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THESIS SUMMARY

Low-carbon energy production is potentially a major method of reducing greenhouse gas emissions and anthropogenic climate change. In the UK, tall perennial grass crops show potential as "biomass crops", providing renewable energy sources with a low net carbon cost. However, conversion of large areas of farmland to biomass production would constitute a major land-use change with possible negative effects on native biodiversity, particularly as some biomass crop types are not native to the UK. The aim of this thesis was to assess biological diversity within mature (>3 years old) crops of non-native *Miscanthus x giganteus* and native *Phalaris arundinacea*.

Biomass crop structural characteristics and management regimes were recorded, and their biodiversity was surveyed with particular reference to birds and small mammals in comparison with adjacent land uses. Food resources in terms of non-crop vegetation and invertebrates were also recorded. Live-trapping revealed eight species of small mammal in the study crops, including a conservation priority species, the harvest mouse *Micromys minutus*, which was most abundant in *Phalaris* crops. *Phalaris* also contained the highest small mammal diversity, but the field headlands held the greatest small mammal abundance. Trapping and direct observations revealed a higher abundance and diversity of birds in the *Miscanthus* crops in comparison with *Phalaris*. Most of the bird species found in biomass crops were associated with woodland or reedbed rather than farmland habitat.

Phalaris crops had a higher percentage of ground cover of the crop itself and non-crop vegetation, whereas *Miscanthus* fields had greater cover of crop litter. *Miscanthus* crops contained fewer invertebrates than *Phalaris* or the field headlands. Management specific to biomass grass crops involves harvest in spring, thus providing winter habitat of importance to birds and small mammals. The crop fields also provide a refuge for invertebrates and non-crop vegetation and overall, supported high levels of biodiversity.

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SPECIES LIST

COMMON NAME	SCIENTIFIC NAME
PLANTS	
Monocotyledons	
Amur silvergrass	*Miscanthus sacchariflorus*
Annual meadowgrass	*Poa annua*
Barley	*Hordeum vulgare*
Bent grass	*Agrostis* spp.
Blackgrass	*Alopecurus myosuroides*
Cocksfoot	*Dactylis glomerata*
Common reed	*Phragmites australis*
Couch grass	*Elymus repens*
Crested dogstail	*Cynosurus cristatus*
False oatgrass	*Arrhenatherum elatius*
Giant miscanthus	*Miscanthus x giganteus*
Giant reed	*Arundo donax*
Guinea grass	*Panicum maximum*
Maize	*Zea mays*
Perennial ryegrass	*Lolium perenne*
Reed canary grass	*Phalaris arundinacea*
Rough meadowgrass	*Poa trivialis*
Sedge species	*Carex* spp.
Smooth meadowgrass	*Poa pratensis*
Soft rush	*Juncus effusus*
Sterile brome grass	*Anisantha sterilis*
Sweet sorghum	*Sorghum bicolor*
Sweet vernal grass	*Anthoxanthum odoratum*
Switchgrass	*Panicum virgatum*
Timothy grass	*Phleum pratense*
Wheat species	*Triticum* spp.
Wild oats	*Avena fatua*
Woodrush	*Luzula campestris*
Yorkshire fog	*Holcus lanatus*
Dicotyledons	
Ash	*Fraxinus excelsior*
Birdsfoot trefoil	*Lotus corniculatus*
Black knapweed	*Centaurea nigra*
Blackcurrant	*Ribes nigrum*
Blackthorn	*Prunus spinosa*
Bracken	*Pteridium aquilinum*
Bramble	*Rubus fructicosus*

COMMON NAME	SCIENTIFIC NAME
Dicotyledons cont.	
Broadleaved dock	*Rumex obtusifolius*
Broadleaved plantain	*Plantago major*
Broadleaved willowherb	*Epilobium montanum*
Common knotgrass	*Polygonum aviculare*
Common orache	*Atriplex patula*
Common poppy	*Papaver rhoeas*
Corn mint	*Mentha arvensis*
Creeping buttercup	*Ranunculus repens*
Creeping thistle	*Cirsium arvense*
Curled dock	*Rumex crispus*
Cut-leaved cranesbill	*Geranium dissectum*
Dandelion	*Taraxacum* spp.
Dog rose	*Rosa canina*
Dove's-foot cranesbill	*Geranium molle*
Fat hen	*Chenopodium album*
Field speedwell	*Veronica persica*
Forgetmenot	*Myosotis* spp.
Goosefoot species	*Chenopodium* spp.
Goosegrass	*Galium aparine*
Great willowherb	*Epilobium hirsutum*
Ground ivy	*Glechoma hederacea*
Hairy bittercress	*Cardamine hirsuta*
Hairy fogfruit	*Phyla canescens*
Hawthorn	*Crataegeus monogyna*
Hedge woundwort	*Stachys sylvatica*
Herb Robert	*Geranium robertianum*
Hogweed	*Heracleum sphondylium*
Ivy	*Hedera helix*
Ivyleaved speedwell	*Veronica hederifolia*
Kenaf	*Hibiscus cannabinus*
Knotgrass	*Polygonum aviculare*
Knotgrass species	*Polygonum* spp.
Lesser burdock	*Arctium minus*
Lettuce	*Lactuca sativa*
Mayweed species	*Matricaria* spp.
Meadow thistle	*Cirsium dissectum*
Mouse ear	*Cerastium fontanum*
Nettle	*Urtica dioica*
Oak species	*Quercus* spp.
Olive	*Olea europaea*
Oxeye daisy	*Leucanthemum vulgare*
Poplar species	*Populus* spp.

COMMON NAME	SCIENTIFIC NAME
Dicotyledons cont.	
Prickly lettuce	*Lactuca serriola*
Ragwort	*Senecio jacobaea*
Raspberry	*Rubus idaeus*
Red clover	*Trifolium pratense*
Redshank	*Persicaria maculosa*
Ribwort plantain	*Plantago lanceolata*
Rosebay willowherb	*Chamaenerion angustifolium*
Scarlet pimpernel	*Anagallis arvensis*
Self heal	*Prunella vulgaris*
Sorrel	*Rumex acetosa*
Sow thistle	*Sonchus oleraceus*
Spear thistle	*Cirsium vulgare*
Spreading hedge parsley	*Torilis arvensis*
Stitchwort	*Stellaria media*
Sunflower	*Helianthus annuus*
Teasel	*Dipsacus fullonum*
Thistle species	*Cirsium* spp.
Thyme-leaved speedwell	*Veronica serpyllifolia*
Upright hedge parsley	*Torilis japonica*
White clover	*Trifolium repens*
Wild strawberry	*Fragaria vesca*
Willow species	*Salix* spp.
INVERTEBRATES	
Armyworm	*Mythimna seperata*
August thorn	*Ennomos quercinaria*
Buff arches	*Habrosyne pyritoides*
Buff ermine	*Spilosoma luteum*
Bumblebee species	*Bombus* spp.
Cinnabar moth	*Tyria jacobaeae*
Comma	*Polygonia c-album*
Earthworm species	*Lumbricus* spp.
Elephant hawkmoth	*Deilephila elpenor*
Fall armyworm	*Spodoptera frugiperda*
Garden tiger	*Arctia caja*
Green veined white	*Pieris napi*
Harlequin ladybird	*Harmonia axyridis*
Honey bee	*Apis mellifera*
Large white	*Pieris brassicae*
Meadow brown	*Maniola jurtina*
Mealworm	*Tenebrio molitor*
Painted lady	*Vanessa cardui*

COMMON NAME	SCIENTIFIC NAME
Invertebrates cont.	
Peach aphid	*Myzus persicae*
Red admiral	*Vanessa atalanta*
Ringlet	*Aphantopus hyperantus*
Rustic	*Hoplodrina blanda*
Shoulder-striped wainscot	*Mythimna comma*
Small copper	*Lycaena phlaeas*
Small phoenix	*Ecliptopera silaceata*
Small square-spot	*Diarsia rubi*
Small tortoiseshell	*Aglais urticae*
Small white	*Pieris rapae*
Speckled wood	*Pararge aegeria*
Western corn rootworm	*Diabrotica virgifera virgifera*
White ermine	*Spilosoma lubricipeda*
AMPHIBIANS	
Common toad	*Bufo bufo*
REPTILES	
Adder	*Vipera berus*
BIRDS	
Barn owl	*Tyto alba*
Barn swallow	*Hirundo rustica*
Blackbird	*Turdus merula*
Blackcap	*Sylvia atricapilla*
Blue tit	*Cyanistes caeruleus*
Bullfinch	*Pyrrhula pyrrhula*
Carrion crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Chiffchaff	*Phylloscopus collybita*
Common redpoll	*Carduelis flammea*
Corn bunting	*Emberiza calandra*
Crow species	*Corvus* spp.
Curlew	*Numenius arquata*
Dunnock	*Prunella modularis*
Eastern great reed warbler	*Acrocephalus arundinaceus orientalis*
Fieldfare	*Turdus pilaris*
Goldcrest	*Regulus regulus*
Goldfinch	*Carduelis carduelis*
Goshawk	*Accipiter gentalis*
Great black-backed gull	*Larus marinus*
Great grey shrike	*Lanius excubitor*

COMMON NAME	SCIENTIFIC NAME
Birds cont.	
Great tit	*Parus major*
Greenfinch	*Carduelis chloris*
Grey partridge	*Perdix perdix*
House sparrow	*Passer domesticus*
Jackdaw	*Corvus monedula*
Japanese reed bunting	*Emberiza yessoensis*
Jay	*Garrulus glandarius*
Kestrel	*Falco tinnunculus*
Lapwing	*Vanellus vanellus*
Lesser redpoll	*Carduelis cabaret*
Linnet	*Carduelis cannabina*
Little owl	*Athene noctua*
Long-tailed tit	*Aegithalos caudatus*
Long-eared owl	*Asio otus*
Magpie	*Pica pica*
Mallard	*Anas platyrhyncos*
Meadow bunting	*Emberiza cioides*
Meadow pipit	*Anthus pratensis*
Mistle thrush	*Turdus viscivorus*
Moorhen	*Gallinula chloropus*
Pheasant	*Phasianus colchicus*
Pied wagtail	*Motacilla alba*
Red-legged partridge	*Alectoris rufa*
Redstart	*Phoenicurus phoenicurus*
Redwing	*Turdus iliacus*
Reed bunting	*Emberiza schoeniclus*
Reed warbler	*Acrocephalus scirpaceus*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Sedge warbler	*Acrocephalus schoenobaenus*
Short-eared owl	*Asio flammeus*
Skylark	*Alauda arvensis*
Snipe	*Gallinago gallinago*
Song thrush	*Turdus philomelos*
Sparrowhawk	*Accipiter nisus*
Starling	*Sturnus vulgaris*
Stock dove	*Columba oenas*
Stonechat	*Saxicola torquatus*
Tawny owl	*Strix aluco*
Tree sparrow	*Passer montanus*
Treecreeper	*Certhia familiaris*
Water rail	*Rallus aquaticus*

COMMON NAME	SCIENTIFIC NAME
Birds cont.	
Wheatear	*Oenanthe oenanthe*
Whinchat	*Saxicola rubetra*
Whitethroat	*Sylvia communis*
Willow warbler	*Phylloscopus trochilus*
Woodcock	*Scolopax rusticola*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Yellow wagtail	*Motacilla flava*
Yellowhammer	*Emberiza citrinella*
MAMMALS	
Bank vole	*Myodes glareolus*
Common shrew	*Sorex araneus*
Common vole	*Microtus arvalis*
Deer mouse	*Peromyscus maniculatus*
Domestic cat	*Felis catus*
Field vole	*Microtus agrestis*
Gray-tailed voles	*Microtus canicaudus*
Harvest mouse	*Micromys minutus*
House mouse	*Mus domesticus*
Meadow vole	*Microtus pennsylvanicus*
Pygmy shrew	*Sorex minutus*
Rat species	*Rattus* spp.
Red fox	*Vulpes vulpes*
Roe deer	*Capreolus capreolus*
Water shrew	*Neomys fodiens*
Weasel	*Mustela nivalis*
Wood mouse	*Apodemus sylvaticus*
Yellow-necked mouse	*Apodemus flavicollis*

CHAPTER 1

GENERAL INTRODUCTION

Abstract

Analysis of surface temperatures and atmospheric carbon dioxide (CO_2) levels over recent years has led to an increasing level of certainty that global warming is linked to anthropogenic activity. In response to this, governments around the world have committed to reducing CO_2 emissions through a range of strategies. One of these strategies is to reduce their dependence on fossil fuels by developing lower-carbon energy supplies through utilising a range of renewable power sources. Energy from biomass has the potential to be a useful low-carbon option, due to the fact that the only carbon released on combustion is equivalent to that fixed during photosynthesis. Biomass crops tend to comprise either woody material grown as short-rotation coppice, or tall perennial grasses. Of the potential biomass grass types, two species are grown in Wales (*Miscanthus* x *giganteus* and *Phalaris arundinacea*).

Concern has also been growing over possible negative effects of agricultural intensification on biodiversity. The abundance of many species that have adapted to traditional farming practices are negatively associated with increasing levels of intensification, which often takes the form of increased homogenisation of the agricultural landscape through the cultivation of monoculture crops and loss of non-cropped habitat.

The potential introduction of large-scale biomass grass crop plantations to the agricultural sector has in turn raised concerns. Some of the grass species grown are not native to the UK and there is very little data available on potential impacts on native wildlife and biodiversity of the crops when they reach maturity and maximum growth. This thesis aims to examine the effects of mature biomass grass plantations on the biodiversity of birds and small mammals and their food resources (non-crop plants and invertebrates).

1.1. Biomass crops as mitigation for anthropogenic climate change

1.1.1 Atmospheric greenhouse gases

The evidence for human-induced climate change has become compelling (IPCC 2007a, and recent reviews e.g. http://berkeleyearth.org/analysis.php). This climate change is being driven by anthropogenic increases in "greenhouse gases" (GHG), which trap the sun's heat within the Earth's atmosphere, increasing global temperatures through their ability to act as an atmospheric "blanket". Global anthropogenic GHG emissions have shown a massive 70% increase between 1970 and 2004 (IPCC 2007b). Infra-red heat radiated from the earth is absorbed by the gases and re-emitted back to the earth instead of escaping back to the atmosphere, resulting in an overall warming effect. These temperature increases are associated with a suite of interrelated climatic changes (e.g. wind and rainfall patterns), oceanographic changes (e.g. sea level rise and potential changes in ocean circulation) and ecological changes (e.g. changes in ranges, phenology and community composition).

CO_2 is one of several greenhouse gases (GHG) attributed to causing global warming. Atmospheric carbon dioxide (CO_2) levels have risen dramatically, by approximately 40% since pre-industrial times from around 280 ppm in 1750 (Intergovernmental Panel on Climate Change IPCC 2007a) to the most recent measurement of 391 ppm for January 2011 (National Oceanic and Atmospheric Administration (NOAA) 2011). Sources of CO_2 resulting from human activities arise from the burning of fossil fuels and the production of cement and other products. Deforestation reduces the number of trees able to absorb atmospheric CO_2 and the deforestation process also releases the gas during ground disturbance and burning (IPCC 2007a). Methane (CH_4) is another major GHG, which although not produced in the volumes that CO_2 is produced during the combustion of fossil fuels, has a warming potential of 3.7 times the equivalent volume of CO_2 (Lashof & Ahuja 1990).

Human-induced CH_4 production includes emissions from the agricultural sector (particularly where ruminants dominate), rice-growing and landfills (IPCC 2007a).

1.1.2 Temperature increases

Between 1906 and 2005, in association with the dramatic increase in GHG levels, the global average surface temperature has increased by around 0.74°C. Of the 12 warmest years on record, 11 occurred in the 12 years between 1996 and 2006 and the two hottest years were 1998 and 2005 (IPCC 2007a). Consequences of global warming include rises in sea level, increased frequency of extreme events such as heat waves, droughts, floods and hurricanes as well as a reduction in snow and ice cover and therefore more heat absorbed by the earth's surface due to reduced albedo (IPCC 2007a). As global temperatures increase, food production will be affected and this is projected to have devastating effects on a growing global human population. Whilst many factors influence climatic processes, the IPCC states a "very high confidence" in the fact that the increase in temperatures since pre-industrial times is due to the effect of human activities (IPCC 2007a).

1.1.3 Mitigation

The signatories of the Kyoto Protocol (1997) have committed to reduce GHG emissions by 5% of 1990 values between 2008 and 2012, but it appears that meeting even this modest target would have very little impact on future climate change. Emissions would need to be reduced to a small fraction of their current levels within the next 100 years to make a significant difference to projected scenarios (Hasselmann *et al.* 2003). Thus, if rapid and harmful climate change is to be avoided, large-scale cuts in GHG emissions would need to be instigated across all spheres of human activity. Measures for reducing GHG emissions from the agricultural sector include the development of soil sinks, reduction in agricultural emissions and development of biofuels as a replacement for fossil fuels (Batjes 1998).

1.1.4 Biomass fuel

The term "biomass" encompasses a wide range of source material and end-products of organic matter origin. Firstly, there are industrial and agricultural waste products, which can be either combusted for heat and power, or bio-digested for the production of biogas. Secondly, multi-functional crops can produce energy in more than one form using different parts of the plant. An example of this type might be wheat, from which the grain can be fermented into bioethanol and the straw can be combusted. Thirdly are the dedicated energy crops such as willow *Salix* spp., poplar *Populus* spp. and perennial grasses, grown specifically for energy production through either combustion or the production of second-generation fuels such as lignocellulosic ethanol (Department for the Environment, Food and Rural Affairs (DEFRA) 2007). There is some interchanging of terms related to biomass energy, but for the purposes of this report, liquid fuels such as bioethanol and biodiesel and also biogas will be referred to as biofuels and woody fuels as biomass.

1.1.5 Biomass energy production as a carbon emission reduction strategy

Energy derived from biomass is not a new concept. Even in present times, millions of people around the globe depend on biomass as fuel, predominantly through the use of wood fuel for cooking although the simple systems used can be inefficient and polluting (European Commission (EC) 2000). In 2000, biomass contributed to 3% of Europe's energy and the intention was to double this total by 2010, which would lead to half of all renewable energy being provided by burning biomass. Eventually it is thought that 20% of Europe's energy could be sourced from biomass, which would require the use of over 20 million hectares (ha) of land to produce energy crops (EC 2000), representing a massive shift in land-use across large parts of the UK. However, the ecological impacts of such a change in land-use are poorly understood and are an increasingly urgent research priority.

The incentives for farmers to start growing biomass crops vary regionally within the UK. In England, establishment grants are made available under the Energy Crops Scheme to farmers who intend to grow a minimum of 3 ha of *Miscanthus* (£800/ha) or short rotation woody coppice (£1,000/ha) for a minimum of 5 years. These grants are dependent on having a local market for the biomass such as a combined heat and power (CHP) plant or on-farm use (Natural England 2007). In Scotland, a one-off payment of £1,000 can be claimed by farmers changing to biomass crops with an end use agreement and also a €45/ha (= approximately £40, October 2011) subsidy for those growing oil seed rape for biofuels (Scottish Parliament 2006).

These grants are not available in Wales and the lack of guaranteed markets for the biomass makes the option of growing energy grasses less attractive to some farmers in comparison with arable crops such as wheat, which has guaranteed markets and good prices available (personal discussions, Royal Welsh Agricultural Society Winter Fair 2007). However, the Welsh Assembly Government (WAG) is committed to investigating the desirability of an establishment grant scheme as part of the One Wales programme and will this be undertaken as part of the Axis 2 Land Management Review (WAG 2008).

The WAG has committed to a reduction in GHG of 3% annually from 2011 as well as increasing renewable energy to 20% of the total energy in use by 2020. There does seem to be some reticence in Wales for embracing biomass as an arable crop rather than using the land for food production, but sustainable development objectives are likely to be met by "local biomass for local energy production" and as such, these schemes are likely to be increasingly prioritised over the coming years. The WAG also aims to aid the installation of micro-generation community projects that include biomass heat or power generation through providing planning guidelines (WAG 2008).

1.1.6 Microalgae and cyanobacteria as biofuels

Another potentially important biofuel source that will only be briefly mentioned here is algae. At present, two approaches exist – one of which harvests algal biomass which is then refined to produce biodiesel, the other is to use cyanobacteria to directly produce ethanol as part of the photosynthetic process (Luo *et al*. 2010). As long as high concentrations of ethanol can be produced in this way, energy inputs and GHG emissions are comparatively low, with the added advantage that fuel production in this 'space-efficient' way will not compete with land needed to grow food.

1.1.7 Second generation processes for producing energy from biomass

Although biomass crops were originally only used for combustion in order to produce heat and power, some second-generation technology is increasing the scope of processes and products for energy generation from biomass. Lignin, cellulose and hemicellulose polymers can be broken down into fermentable sugars by chemical processes (using dilute acid or alkaline) or enzymatic processes and then fermented into ethanol (Foyle *et al*. 2007). Additional carbon costs involved in processing biomass for lignocellulosic ethanol partly depend on the process used (Slade *et al*. 2009). The use of ammonia pre-treatment has been proposed as an alternative to acid or alkaline hydrolysis (Huyen *et al*. 2010). This achieves an increased porosity in the biomass material and removes lignin and hemicelluloses, allowing subsequent enzyme activity to be more effective.

Enzyme conversion is a more efficient method for producing ethanol than dilute acid conversion, but more electricity is used in the manufacture of the enzymes, with the result that this latter process could be responsible for higher GHG emissions than the former (Slade *et al*. 2009). Despite this, the lignocellulosic supply chains in the study (by Slade *et al*. 2009) would lead to reduced GHG in comparison with gasoline fuel.

Another technology under development is pyrolysis (fast or slow), which involves heating biomass in the absence of oxygen to produce the liquid product "bio-oil". This can be used instead of mineral oil for generating power and has the advantage of being easily transported in its liquid form (Hodgson *et al*. 2010a). Carbon savings from biomass grown for slow pyrolysis were enhanced when the by-product of pyrolysis, "biochar" was applied to agricultural soils (Gaunt & Lehmann 2008). Biochar can also increase the productivity of soils by facilitating the uptake of nutrients by plants, and also enhances the soil structure and biological properties.

1.1.8 Perennial grass types

Four main types of perennial grass have been identified as potentially good biomass sources in Europe: *Miscanthus* x *giganteus*, reed canary grass *Phalaris arundinacea*, giant reed *Arundo donax* and switchgrass *Panicum virgatum* (Lewandowski *et al*. 2003). *Miscanthus* and switchgrass both have C4 photosynthetic pathways and *Phalaris* and giant reed are both C3 plants although the photosynthetic rates in giant reed are higher and biomass production is similar to C4 plants (Cosentino *et al*. 2006). The advantages of using rhizomatous grasses include the fact that nutrients are translocated to the rhizome at the end of the growing season and the resulting senesced stem material has a lower mineral content and produces less pollution when combusted (Heaton *et al*. 2004).

Plantations of only two of these grasses (*Miscanthus* and *Phalaris*) were available in the required geographical area (mid and west Wales) and therefore for the purposes of this thesis, only these two biomass grass types are considered.

1.1.9 Markets for biomass

An essential element of growing biomass crops as a renewable energy, is that there is a viable market for the crop that is sufficiently local, to minimize transport-induced CO_2 emissions. Increasingly, biomass boilers are being used for small scale

heat generation in domestic and agricultural settings. On a medium scale, combined heat and power plants can be used in a community setting, or for commercial premises (as at Bluestone Holiday Park in Pembrokeshire, South Wales). On a larger scale, co-fired power stations are able to burn biomass in combination with coal. There are currently 15 such power stations in the UK, with Aberthaw in South Wales having a total capacity of 1,455 MWe (DTI 2005). In 2005, energy crops (*Miscanthus* and short rotation coppice (SRC) willow) accounted for only 0.3% of the total biomass feedstock co-fired with coal, but their transport-related emissions were the among the lowest of all biomass types used, at 1.7 kg CO_2 / tonne biomass (DEFRA 2007).

1.1.10 Properties of good biomass for combustion

Plant material that is too high in nutrients and alkali inorganic elements can cause damage to power plants through slag formation, fouling and corrosion (Monti *et al*. 2008). These processes occur through accumulation of deposits on heat exchangers which reduces their efficiency, or by chemical reactions between products of combustion and the metal surfaces of the power plant, causing damage. Material high in ash content can also reduce the energy output and it is therefore important to ensure that attention is paid to ensuring the best biomass quality (Monti *et al*. 2008).

1.2 *Miscanthus*

1.2.1 *Miscanthus* - description and agronomy

Miscanthus x *giganteus* Greef & Deuter ex Hodkinson is a sterile allopolyploid hybrid produced by crossing *Miscanthus sinensis* with *Miscanthus sacchariflorus* (Stewart *et al*. 2009). The native range of these two species is East Asia, where their use as grazing and thatching material is well established (Stewart *et al*. 2009). *M. sinensis* has a high tolerance for heavy metals and acid soils but it is unknown whether this trait is also present in *M.* x *giganteus*. If it were, or if *M. sinensis* were

to be grown as a biomass crop in its own right, there is a possibility that it could be grown on contaminated land (Stewart *et al*. 2009).

M. x *giganteus* (hereafter referred to as *Miscanthus*) has a C4 photosynthetic pathway (Farrell *et al*. 2006), resulting in a higher water use efficiency than C3 plants. As it cannot produce viable seed, propagation has to be via rhizomes planted directly into the ground, or through the raising of plantlets in greenhouses (Lewadowski & Schmidt 2006). In order to maximise production of the crop, it is crucial to establish planting at high density. This arises from the fact that establishment of planted rhizomes can be poor and depends on many different factors, including age of the rhizomes, ground preparation and subsequent weed control (Atkinson 2009). It is therefore recommended that rhizomes are planted at a density of 20,000 ha^{-1} in spring and that particular attention is paid to weed control in the first couple of years (DEFRA 2001). Planting can either be achieved using a modified potato planter or by broadcasting the rhizomes using a muck spreader, although more uniform planting rates are achieved by the former (DTI 2003).

Pre-emergence herbicides and those specifically targeting broadleaved weed species do not damage *Miscanthus* plants or reduce the biomass produced, whereas herbicides with grass activity cause significant damage and as a consequence, a reduction in biomass (Anderson 2010). Growth begins from the dormant rhizome when soil temperatures reach 10-12°C (Lewandowski *et al*. 2003) and the threshold for photosynthesis is 6°C, which allows a longer growing season than the other C4 plant commonly grown in the UK: maize *Zea mays*. *Miscanthus* may be vulnerable to spring frosts, with an LT_{50} (lethal temperature at which half the shoots are killed) of -6°C. Other hybrids may have better cold tolerance, but at the expense of reduced biomass production at higher temperatures (Farrell *et al*. 2006). Breeding trials are currently underway in order to select genotypes with late flowering

tendencies, in order to delay the onset of senescence and therefore maximise biomass production (Jensen 2009).

Miscanthus was found to produce significantly more biomass than switchgrass in a varied range of growing conditions, although yield was constrained by water rather than nitrogen availability (Heaton *et al.* 2004). Yields of 10-15 t DM ha^{-1} a^{-1} have been achieved in the UK, but up to 44 t DM ha^{-1} a^{-1} in Southern Europe (Lewandowski *et al.* 2003).

Once established, the rhizomes grow outwards underground, from which a closely packed clump of stems grow (Figure 1.1).

Figure 1.1 Stages of growth of the *Miscanthus* crop through the year. Clockwise from top left: April, June, October and January

By the end of the growing season in the UK, crop height can be around 3 m and can be harvested annually from the first growing season after planting, although yield doesn't reach maximum production until around three years after planting. Unlike switchgrass, *Miscanthus* is still actively growing by October (Heaton *et al.* 2009). The crop is usually left standing over the winter, by which time most of the minerals and nutrients within the plant tissues are relocated to the rhizomes (Lewandowski & Schmidt 2006).

The leaves also senesce and fall to the ground at the end of the growing season, leaving mainly dry stems/canes, which can comprise up to 92% of harvested dry matter (Christian *et al.* 2008). Senesced leaves provide organic inputs to the soil, estimated from models to be 0.93 t C ha a^{-1} (Clifton-Brown *et al.* 2004). Once planted, the soil is undisturbed for the life of the rhizomes, resulting in less risk of soil erosion and soil organic carbon loss through the annual ploughing required for other arable crops (Lewandowski *et al.* 2003).

1.2.2 Fertilizers, productivity and longevity

The lifetime of a single planting of annually-harvested *Miscanthus* is estimated to be 20 years (DEFRA 2001), and a crop in silty loam soil has been recorded as continuing to be productive after 14 years with no additional fertilizers (Christian *et al.* 2008). As a result of nitrogen (N) fertilizer use, corn-based agrosystems are responsible for emitting substantially higher quantities of GHG (CO_2, nitrous oxide N_2O and CH_4) than any alternative biofuel crop, and out of the potential crops investigated by Davis *et al.* (2010), *Miscanthus* was found to be the crop with the lowest GHG emissions.

It has been suggested that part of the nitrogen (N) efficiency of *Miscanthus*, requiring little or no fertilizer input to the crop, is linked to some kind of biological N-fixation ability (Davis *et al.* 2010). *M. sinensis* has been shown to have an

association with arbuscular mycorrhizal fungi, which are thought to aid assimilation of both N and phosphorus (P), and endophytic fungi may also contribute N to the plant (Stewart *et al*. 2009). In *Miscanthus*, the greatest N use efficiency was seen when only soil N was available and no inorganic fertilizer was used (Lewandowski & Schmidt 2006). In addition to this, when compared with triticale and *Phalaris*, *Miscanthus* was also classified as having the best energy and land efficiency (energy produced per unit land area) – all of which were attributed to its C4 photosynthetic process making the most efficient use of available nutrients and water (Lewandowski & Schmidt 2006). Miller (2010) found that *Miscanthus* was second only to sugarcane *Saccharum* spp.in terms of land use and nitrogen efficiency when compared with 13 other potential biofuel crops ranging from algae to cereals and woody biomass.

Studies on the effects of artificial fertilizers have produced some conflicting results. Christian *et al*. (2008) reported no effect of N fertilizers on yield of *Miscanthus*, but recommended a small yearly application of P in order to reduce the risk of depleting soil reserves. Lewandowski & Schmidt (2006) found that N fertilization increased biomass yield, but that N applications of more than 114 kg N ha^{-1} were harmful to the *Miscanthus* plants. However, their study did not include analysis of the mineral content of the biomass, which can be influenced by fertilizer use (see also section 1.3.2 on the effects of fertilizer on *Phalaris*). Smith & Slater (2010) found a significant increase in biomass yield in response to organic and inorganic fertilizers, but only in the second year of use, suggesting that a time-lag existed before the nutrients were utilised by the plant to any great extent.

The use of artificial fertilizers also has implications for the quality of the biomass for pyrolysis. Application of nitrogen fertilizer in high quantities reduced the cell wall components and increased the ash content, making it a less suitable feedstock for pyrolysis than biomass produced at low N-fertilization rates (Hodgson *et al*.

2010a). The low nitrogen treatment also resulted in a higher proportion of the desired organic volatiles, which gave a better quality of pyrolysis liquid. A higher viscosity and increased heating value were also seen, attributed to the quantity of lignin within the biomass (Hodgson *et al.* 2010a).

A further positive attribute of *Miscanthus* plantations is their ability to decrease nitrate load to watersheds, which is proportionally more effective than reduction in N fertilizer use alone (Ng *et al.* 2010).

1.2.3 Timing of *Miscanthus* harvest

Harvest usually occurs between January and March and a relatively low moisture content of 25-50% is achieved depending on the harvesting method used (DEFRA 2001). Harvesting in spring (rather than late autumn or winter) can result in a reduction in the quantity of biomass over the winter, resulting from degradation of the material by the weather conditions (Heaton *et al.* 2009). This loss has been estimated as being from 23-51% of total biomass produced and is comprised of fallen leaves and stubble residues (Kahle *et al.* 2001).

Once the harvested crop is baled, it is recommended that *Miscanthus* is stored under cover in order to keep moisture content stable and prevent degradation of the material (Nolan *et al.* 2009).

Timing of harvest can also affect the quality of the biomass for combustion due to the movement of minerals around the plant tissue. In general, the concentration of minerals within the plant tissues is highest in the late spring and early summer. At the end of the growing season, minerals are remobilised to be stored in the *Miscanthus* rhizomes over the winter and are then available for new growth in spring (Christian *et al.* 2008). The N content of standing *Miscanthus* biomass showed a significant reduction over time, although there was no further significant

reduction between December and February/March (Heaton *et al*. 2009). With a nutrient content of 0.6% [N] being the accepted upper limit for combustion, for reasons of minimising pollution, the *Miscanthus* biomass was suitable as power station feedstock by December, when N levels fell below this threshold, even though N content had been higher in the summer (Heaton *et al*. 2009). Jorgensen (1997) reported similar results, with 0.59% [N] in spring-harvested *Miscanthus*, which was lower than the concentration found in *M. sinensis*. Conversely, potassium (K) and chlorine (Cl) levels diminished to a greater degree in *M. sinensis* during the winter, which was thought to be because the plants senesced after the initiation of flowering, which did not occur in *M.* x *giganteus* (Jorgensen 1997). Cl and sulphur (S) are elements with the potential to cause corrosion and pollution during combustion. Compared with giant reed and sweet sorghum *Sorghum bicolor* in this respect, *Miscanthus* and switchgrass had the best overall quality (Monti *et al*. 2008). Later harvest may also affect this - it is thought that rain may leach K and Cl from the dry biomass before harvest, as this has been reported in straw (Christian *et al*. 2008; Sander 1997). In *M. sinensis*, the concentration of silica (Si) rises towards the end of the growing season, and this may have implications for *Miscanthus* harvest time (Stewart *et al*. 2009).

Earlier harvests in December have been shown to increase energy yields, but result in higher sulphur dioxide (SO_2) emissions during combustion, thus increasing the pollution produced (Lewandowski and Heinz 2003). Even delayed harvest in spring may not produce consistent quality of fuel for combustion, as early frost or other factors that affect the remobilisation of minerals can influence biomass quality at harvest (Christian *et al*. 2008).

Balancing the effects of winter weather on loss of biomass yield against reduction in N content of the biomass need to be considered on a local scale, as climatic

conditions and soil nutrient level vary between the areas where biomass crops are grown (Heaton *et al*. 2009).

Work on pyrolysis of *Miscanthus* does not seem to include differences incurred by different harvest dates. However, a study on switchgrass found that the energy content of the products of pyrolysis were around 80% for later harvested biomass and only 68% for material harvested earlier (Mohan *et al*. 2006).

A different harvest date might also be required for *Miscanthus* intended for lignocellulosic ethanol production. Hodgson *et al*. (2010b) reported higher lignin and hemicellulose content from winter harvests in comparison with biomass harvested in autumn. The greatest proportion of soluble compounds are found in the leaves, and delayed harvest led to a reduction in leaf quantity available for processing (Huyen *et al*. 2010). The cell wall proportion of the biomass was also higher when late harvest took place, but compounds such as glucan did not change from early harvest levels. In general, saccharification yields were reduced after late harvest compared with earlier harvest, thought to be influenced by the biomass cell wall phenolic fraction (Huyen *et al*. 2010).

1.3 *Phalaris*

1.3.1 *Phalaris* description and agronomy

Phalaris arundinacea L. (Figure 1.2) is a plant native to Eurasia and North America, commonly found in damp areas. Crops are sown by either broadcasting or drilling seed and can be harvested using machinery (such as forage harvesters) usually used for grass or hay (Landström *et al*. 1996). As it is propagated from seed and germinates slowly, it is likely to suffer some weed competition initially, although after its first year of growth, it is highly competitive against weeds so that herbicides should no longer be required. It can survive waterlogged soils and yet is also more resistant to drought than other grasses (Lewandowski *et al*. 2003).

Figure 1.2 The different phases of *Phalaris* crop growth through the year. Clockwise from top left: April, July, November and February

Phalaris is the indigenous grass thought to produce the best biomass yields for Northern Europe and has been studied widely in Scandinavia, where it has been cultivated for forage and hay for livestock for many years (Andersson 2000). Although local forms of *Phalaris* are abundant, they do not grow as tall as some of the developed cultivars (Sahramaa & Jauhiainen 2003). At seed ripening, *Phalaris* cultivars had grown to 98% of their maximum height, a process that took 95 days in Finland. The advantages of growing *Phalaris* in the UK are that it is adapted to both the local climate and growing season length, its rhizomes are able to survive the winters and it shows good genetic variability and hence less vulnerability to disease (Lewandowski *et al*. 2003).

The use of *Phalaris* as a biomass energy source was first initiated in Scandinavia in the late 1990s, when it was co-fired with wood waste in biomass energy plants. In 2004, bioenergy accounted for 21% of energy used in Finland (Pahkala *et al*. 2008)

and the Finnish government is committed to supporting production of *Phalaris* and other biomass energy crops. It is also grown in Estonia, where the climate and growing season are not appropriate for *Miscanthus* or Poplar *Populus* spp.coppice, but where *Phalaris* is adapted to local conditions and grows well (Heinsoo *et al*. 2011). In northern latitudes, areas of organic soil where peat extraction has ceased are thought to be at risk of losing high levels of soil carbon as they dry out (Shurpali *et al*. 2009). *Phalaris* is often planted in these areas as the wet, humus-rich soil is thought to be suitable for its cultivation. Heinsoo *et al*. (2011) found that biomass yields were higher on mineral soils than depleted organic soils, but where the aim was to retain soil carbon rather than maximise biomass yield, organic soils planted with *Phalaris* were a net sink of carbon (Shurpali *et al*.. 2009).

High content of ash and alkali metals in biomass can cause problems during combustion, as well as creating additional pollution (Burvall 1997). Soil type and quality can influence these factors and need to be taken into consideration when producing biomass for combustion (Paulrud *et al*. 2001). Mineral soils, particularly those with a high clay content resulted in the *Phalaris* biomass producing more ash than was produced on organic soils (Heinsoo *et al*. 2011; Finell & Nielson 2005; Burvall 1997; Landström *et al*. 1996).

Clay soil also increased lignin content of the biomass at the expense of glucose and xylose, a factor which could be of importance if the material was used for lignocellulosic ethanol production (Finell *et al*. 2010). Breeding programmes for *Phalaris* cultivars may result in improved biofuel quality through selection for increased cell-wall content and improved productivity (Wrobel *et al*. 2009)

1.3.2 Fertilizers, productivity and longevity

In Finland, it is common practice to use fertilizer on *Phalaris* crops in organic soils (Shurpali *et al*. 2009). However, it has been shown that such applications do not increase growth of the crop, but in fact increase levels of N, P, K and S in harvested material, which make it less suitable for combustion (Katterer *et al*. 1998). The Estonian study included some semi-natural *Phalaris* stands where no fertilizer was used because of conservation management plans but there was no difference in energy yield between these unfertilised stands and the commercially grown crops (Heinsoo *et al*. 2011). A study using a range of organic and inorganic fertilizers also found no difference between treatments in growth rates of *Phalaris* for either field or pot trials, although harvested biomass contained significantly higher levels of nutrients (Smith & Slater 2010), reflecting the findings of Katterer *et al*. (1998). In contrast to this, Lewandowski & Schmidt (2006) found that increasing levels of N fertilization continued to increase *Phalaris* biomass yields, but they made no analysis of the quality of the material produced in this way.

Potential life-span of a *Phalaris* crop appears to vary. Experimental areas of the crop in Finland are still productive after 16 years (Pahkala *et al*. 2008) but on more organic soils, typical rotations last for 10 years (Shurpali *et al*. 2009).

1.3.3 Timing of harvest

Burvall (1997) found that delaying harvest until spring resulted in lower concentrations of Cl, alkali and S in the *Phalaris* biomass. This late harvest practice was originally introduced in Sweden to coincide with the melting of the snow that has covered the fields over the winter, and before new growth had begun (Finell *et al*. 2010). Although a harvest in spring rather than the autumn results in a loss of biomass of up to 16 % (Heinsoo *et al*. 2011), the additional time allows increased nutrient translocation to the rhizomes (Xiong *et al*. 2009) and reduces the requirement to fertilize the crops (Finell *et al*. 2010). Landström *et al.* (1996) also

reported that K and Cl leached from the dry matter during the winter and thus their levels were lower at spring harvest than in autumn.

It was deemed to be physiologically better for the plant to be allowed to grow unhindered for the whole growing season. Harvest in August resulted in no re-growth, despite this potentially being possible until the end of October (Landström *et al*. 1996). Delayed harvest was also examined in terms of its effects on carbohydrate composition of the biomass. Heinsoo *et al*. (2011) reported a higher calorific value for the *Phalaris* biomass in spring than in summer or autumn, but this benefit was countered by the loss of biomass. They concluded that the conditions in which *Phalaris* crops are grown in Estonia dictate that harvest in autumn provides more optimal yields than in spring.

1.4 Considerations for both grasses

1.4.1 Stem content

A high proportion of stems in the harvested biomass of both *Miscanthus* and *Phalaris* crops is important to its quality, as when combusted, less ash is produced by stems than leaves (Christian *et al*. 2008; Monti *et al*. 2008; Landström *et al*. 1996). A significant proportion of N within the *Miscanthus* is stored in the leaves, which is returned to the soil when the leaves fall. This also contributes to a lower proportion of N in the harvested stems, improving the quality of the combustible biomass (Heaton *et al*. 2009). Cellulose and lignin are found in higher proportions in the *Miscanthus* stems but hemicellulose concentrations are higher in the leaves (Hodgson *et al*. 2010a).

1.4.2 Lodging

Lodging, where stems bend, causing the crop to 'fall over' can become a problem with late harvesting and result in a smaller harvest of *Phalaris* (Pahkala *et al.* 2008). The weakness of stems that leads to lodging was thought to be responsible for

reduced productivity, particularly in irrigated crops. This led Katterer *et al*. (1998) to conclude that unless stem stiffness could be improved through selective breeding, it was unlikely that *Phalaris* could be a contender against other biomass crops grown intensively at lower latitudes. In a UK study, Riche (2006) also reported lodging in *Phalaris*, resulting in some wet biomass at harvest, but did not deem it a major problem.

Where an increase in above-ground *Miscanthus* biomass occurred as a result of high levels of nitrogen fertilization, there was also an increased incidence of lodging, which was not seen at lower fertilization levels (Kaack & Schwarz 2001). *Miscanthus* stems seem more robust in rain and wind than *Phalaris*, bending severely but then springing back to their previous position. Heavy snow on the other hand can cause the stems to irreversibly bend and lodge, causing difficulty in subsequent harvesting (Richard Collins - personal communication, also Figure 1.3).

Figure 1.3 *Miscanthus* in Herefordshire, where heavy snowfall in winter 2007/8 caused lodging of the stems.

1.4.3 Carbon balance and future climate scenarios

The effect of planting biomass crops on soil carbon stocks is dependent on soil type, climatic conditions, prior land management and previously cultivated vegetation (Hillier *et al*. 2009). *Miscanthus* plantations have been reported as contributing significant quantities of organic carbon (11.7 t ha^{-1}) to the soil in which they are grown (Kahle *et al*. 2001). One of the ways in which this is achieved is via the significant losses of dry matter incurred both before and during harvest, which contribute significant quantities of carbon to the soil (Hansen *et al*. 2004). Less work appears to have been done on the effects of *Phalaris* on soil organic carbon, although Shurpali *et al*. (2009) reported a net carbon sink in organic soils planted with *Phalaris*.

Monti *et al*. (2009) found that replacing conventional (annual) arable rotations with perennial energy crops resulted in an average 50% lower impact on soil carbon stocks. Dondini *et al*. (2009) reported that *Miscanthus* crops grown on land previously under arable cultivation led to an increase in soil organic carbon to a level above native pasture.

Cultivation of *Miscanthus* on grassland led to initial soil organic carbon (SOC) losses, but this was soon replaced by carbon sequestered by the crop (Anderson-Teixeira *et al*. 2009). This organic matter was found to be as stable as that produced by C3 grassland and the longer that *Miscanthus* was cultivated, the time taken for the organic carbon to be mineralised was increased (Dondini *et al*. 2009; Foereid *et al*. 2004). The impact of earthworms (suborder Lumbricina) on the decomposition and mineralisation of energy crop residues was investigated by Ernst *et al*. 2009. They found that litter decay was highest in maize residues and lowest in *Miscanthus*, which had C:N ratios of 35 and 134 respectively. They concluded that competition for N between soil microorganisms and earthworms could lead to slower decomposition rates. *Miscanthus*-derived SOC also contains higher

proportions of alkanes, alkenes, sterols and free fatty acids (Kahle *et al*. 2001) and both these factors could contribute to the apparent recalcitrant nature of the SOC reported by Dondini *et al*. (2009) and Foereid *et al*. (2004). It was also reported that harvest of biomass slowed the accumulation of organic carbon in the soil under the crops (Foereid *et al*. 2004) demonstrating the very fine balance within the soil organic carbon sequestration system. It was estimated that 26-29% of cumulated carbon input from *Miscanthus* was retained in the soil in 16 year old stands (Hansen *et al*. 2004), but Hillier *et al*. (2009) found that soil carbon accumulation eventually stopped. A hectare of grassland replaced by *Miscanthus* reached equilibrium after about 15 t of carbon was sequestered and then no further changes in soil C stocks occurred after this point. The majority of *Miscanthus*-derived carbon was found in the top 50 cm of the soil (Hansen *et al*. 2004).

Some authors argue that the replacement of natural ecosystems with biomass crops could cause a net source of carbon that would not be counterbalanced by the biofuel benefits (Monti *et al*. 2009). Hughes *et al*. (2010) modelled the effects of large-scale *Miscanthus* plantations on atmospheric CO_2 concentrations. They found that there would be an initial 'carbon payback' time of 30 years for the *Miscanthus*, but that by the end of the century there could be a possible reduction in CO_2 emissions of between 162 and 323 ppmv if fossil fuels were to be replaced by *Miscanthus*. However, their initial model did not take into account natural carbon displacement through land use. When this was taken into account, they predicted that it would take at least until 2046 before net CO_2 levels were lowered as a result of using *Miscanthus* in the place of fossil fuels (Hughes *et al*. 2010).

The current target of the UK government is to increase the area of biomass crops to 1.1 million ha by 2020, and Haughton *et al*. (2009) suggest that in England alone, an area of 3.1 million ha suitable for planting biomass crops is available. Biomass sceptics argue that land used for biomass is land taken away from food production,

but it should be possible to grow biomass on land that is of lower quality for agriculture and therefore the conflict need not arise (Bauen *et al*. 2010; Solomon 2010; Lovett *et al*. 2009).

If the climate were to warm significantly, this may have negative impacts on the growing of many different kinds of crops in the UK. If rainfall was reduced, then food crops such as oats, rye and potatoes may be restricted to more northerly agricultural areas (Bellarby *et al.* 2010). These authors also modelled effects on *Miscanthus*, finding that it was only likely to be adversely affected in South East England, but that new biomass or bioenergy crops such as sunflower *Helianthus annuus*, kenaf *Hibiscus cannabinus* and olive *Olea europaea* could be introduced in its place. Tuck *et al*. (2006) predict that the area suitable for growth of *Miscanthus*, *Phalaris* and SRC could increase by 50% as their range moves northwards, and even suggests that *Phalaris* and SRC could be grown above latitudes of 65° north.

Rises in atmospheric CO_2 are largely predicted to enhance photosynthesis and therefore the productivity of C3 plants (Leakey 2009). C4 plants such as *Miscanthus* do not benefit from raised CO2 levels, unless drought stress is present, in which case the higher intracellular CO2 levels and increased stomatal resistance maintain photosynthetic rates (Leakey 2009).

1.4.4 Invasiveness

Introductions of non-native plant species can carry a risk of escape and subsequent classification as an invasive pest species. Barney & Di Tomaso (2008) used a weed risk-assessment tool to assess possible invasiveness of biomass grasses in the USA. They concluded that possible effects varied across regions, but that switchgrass had invasiveness potential in California due to its large production of small seeds, ability to grow from pieces of plant material and ability to tolerate a wide range of environmental conditions. Giant reed was thought to have potential invasive risk in Florida, as it has already escaped and naturalised in Texas and California, where

it is listed as a noxious weed. Hybrid *Miscanthus* cultivars were not deemed to carry any risk of invasiveness in the USA due to their inability to set viable seed (Barney & Di Tomaso 2008). *M. sinensis* on the other hand has escaped over a long period of time in the Appalachian region in the USA and is therefore not recommended for use as a biomass crop unless a sterile variety can be developed (Quinn *et al*. 2010).

In the USA, an invasive genotype of *Phalaris* in wetland has caused problems for local biodiversity (Wrobel *et al*. 2009) and as such has been used as a model system to study botanical invasiveness (Lavergne & Molofsky 2004).

1.4.5 Economics and farmer attitudes

Many factors are involved in the growing of biomass, which is still a relatively new form of renewable energy that requires specific markets for its use, whether through combustion for heat and power or lignocellulosic ethanol production. Different crops are better suited to some regions than others, and this in turn will affect the economics involved. Aravindhakshan *et al*. (2010) compared crops of switchgrass and *Miscanthus* in Oklahoma, USA. They found that switchgrass, harvested once annually, outperformed *Miscanthus* in terms of biomass and energy yield. However, in the absence of suitable economic subsidies, carbon taxes or mandatory targets for biomass production, it was not deemed economically competitive to produce electricity from biomass in that region (Aravindhakshan *et al*. 2010). A similar conclusion was drawn by Bocqueho & Jacquet (2010), when they compared biomass production from the same two grasses with traditional arable rotations of wheat, barley and oil-seed rape in Central France. Despite this, if economic incentives for biomass production were offered to farmers, the biomass grasses were attractive as diversification crops (Bocqueho & Jacquet 2010).

Farmers contracted by energy companies to grow *Phalaris* in Finland were enthusiastic about it as a crop, with 55% seeking to grow more than originally contracted (Pahkala *et al*. 2008). The main reason for growing *Phalaris* was related to the lower workloads involved and the most common problem encountered was control of perennial weeds during establishment of the crop.

1.4.6 Pests and diseases

In general, *Miscanthus* is considered to be of low risk for pests and diseases in the UK due to it being a non-native species. However, it belongs to the sorghum tribe (Andropogoneae) along with other crops such as maize and sugar cane and could therefore be susceptible to pests and diseases already adapted to these crops (Stewart & Cromey 2010).

In the USA, there have been reports of aphid infestations in *Miscanthus* plantations (Bradshaw *et al*. 2010), and the fall armyworm *Spodoptera frugiperda* shows the ability to develop on *Miscanthus* leaves under laboratory conditions (Prasifka *et al*. 2009). Spencer & Raghu (2009) also raise concerns that *Miscanthus* grown in the same location as maize may become a reservoir for the western corn rootworm *Diabrotica virgifera virgifera*. Both the fall armyworm and western corn rootworm showed lower emergence rates and adult weights on *Miscanthus*, suggesting that they would be less likely to favour it in the presence of their preferred host plant. However, the ability of either of these pests to cause economic damage in commercial crops is as yet unclear.

The susceptibility of *M. sinensis* and *Phalaris* to two isolates of barley yellow dwarf virus (BYDV) and one isolate of cereal yellow dwarf virus (CYDV) was tested by Lamptey *et al*. (2003). They reported that *M. sinensis* infection only occurred with one isolate of BYDV and *Phalaris* by one isolate each of BYDV and CYDV, but that infection rates slowed as plant growth increased.

1.5 Other uses for perennial grass crops

1.5.1 Animal bedding

Phalaris has been investigated as a potential bedding material, particularly in areas where there is very little arable production and costs of obtaining cereal-crop straw are high (McLean 2007). It was found to be a viable alternative to straw, especially if it could be produced on-farm and had no negative impacts on the condition, productivity or behaviour of the livestock housed on it (Morgan 2008, McLean 2007).

1.5.2 Animal fodder

Nutrient composition of *Phalaris* hay matched that of Timothy *Phleum pratense*, but was less digestible to horses, which also showed a preference for Timothy in terms of voluntary dry matter intake (Ordakowski-Burk *et al*. 2006). ADAS (2008, unpublished) undertook to determine how sheep (specifically ewes) fared whilst grazing on *Phalaris* re-growth during late autumn, following an August harvest of the biomass. The grazing trial lasted for one month, during which times the rams ran with the flock in order to commence breeding. When compared with ewes grazing on permanent grass ley, the ewes grazing on *Phalaris* showed no significant differences in terms of body mass at the end of the trial, or numbers of lambs produced the following spring.

1.5.3 Phytoremediation

Phalaris has been shown to be of use for wastewater treatment when planted in artificially constructed wetlands, where its growth is equivalent to that of natural stands (Vymazal & Krőpfelová 2005). *Phalaris* was also found to be superior to common reed *Phragmites australis* in the treatment of dredged sludge contaminated with heavy metals (Seidel *et al*. 2004).

1.5.4 Phytochemicals

Increasingly, alternatives to various substances that rely on fossil-based oil for their manufacture are being sought. Villaverde *et al.* (2010; 2009) reported on a process for fractionation of phenolic compounds (e.g. syringaldehyde, vanillic acid, vanillin and p-coumaric acid) from *Miscanthus*. These monomers can reduce the quality of pulp for paper, but are also thought to have value if they can be refined for pharmaceutical use.

1.6 Biodiversity and biomass crops: an introduction

1.6.1 Biodiversity and land use change

Loss of biodiversity is a worldwide problem, which can be attributed to a number of factors, including intensification of agriculture and forestry. One of the ways of intensifying agricultural output is to turn to monocultures, which reduce structural complexity at a crop and landscape level, and as a result, can reduce the biodiversity present within the agricultural landscape (Tscharntke *et al.* 2005). Intensification can take place at local, landscape and even continental levels and can take varying forms as a result of changed land-management, as shown in Table 1.1.

Table 1.1 Changes in agricultural practices at local and landscape levels (adapted from Tscharntke *et al.* 2005)

Local intensification	Landscape intensification
Simplification of crop rotations and change of sowing time	Change from mixed farming to monoculture arable crops
Increased input of fertilizers and pesticides	Loss of permanent pasture, old fallows and edge habitats
Monocultures of high yield varieties and GM crops	Increases in field size and fragmentation of natural habitat
Larger fields and deeper ploughing	

Agricultural intensification can also lead to loss of ecosystem services and processes such as biological pest control, crop pollination, grassland production and resistance

to plant invasion (Tscharntke *et al.* 2005). However, it is recognised that if energy crops can be grown on degraded or abandoned land and if only minimal soil disturbance takes place, there may be positive impacts on biodiversity and ecosystem services (United Nations Environment Programme (UNEP) 2008).

More detail about the effects of agricultural intensification on invertebrates, non-crop vegetation, birds and small mammals are discussed in Chapters 2 – 5.

1.6.2 Impact on wildlife of biomass grass crops

Growing energy grass crops is a relatively new option available to farmers. This presents a good opportunity for the impact of growing mature biomass crops on biodiversity to be studied before they become widespread as a monoculture. Many attributes of the crops could create positive impacts on wildlife. For example, they are perennials and apart from the harvesting process, there is very little disturbance to the land for the rest of the year. Chemical inputs such as fertilizer and pesticides are minimal once the crop is established and could lead to the crop becoming a valuable refuge for invertebrates. The crops add architectural complexity to the landscape and as the senesced crop is left standing over winter, shelter for birds and mammals could be provided at a time when most other crops or swards are at minimal heights. Spring harvest of biomass crops results in bare ground being available at a time when ground nesting birds require it and may also support non-crop vegetation diversity, increasing the complexity of the crop as a whole. Finally, assuming the crops are grown within a conventional hedged field structure, there is potential for uncultivated "conservation headlands" to be retained between the crop and the surrounding hedges. These headlands do not require any management and will provide additional food resources and shelter, likely to boost biodiversity.

The annual cropping cycle involves minimal intervention and results in the crops being undisturbed for much of the year. Thus, the biomass crops may provide

refuge for wildlife throughout the summer and winter (Price *et al*. 2004). Although many positive effects of biomass crops on wildlife have been reported, these appear to be dependent on factors relating to management and age of the crops (Dauber *et al*. 2010). For example, Semere & Slater (2005) reported some benefits for wildlife in newly established biomass grass crops (of up to three years old), although in general the field margins contained greater diversity than the crops themselves. At the commencement of this project, no other work on more mature crops had been published.

1.7 Aims of this thesis

Aim 1. To investigate bird and small mammal abundance and diversity within *Miscanthus* and *Phalaris* crops (of 3 years and older) and their headlands as well as adjacent comparison sites representative of local land use prior to biomass crops being grown using the following techniques:

(a) Live capture/release of small mammals using Longworth traps

(b) Mist net capture/release and walking transects surveys of birds

(c) Animals were identified to species and diversity indices calculated.

Aim 2. To investigate food resources (invertebrates and non-crop vegetation) for birds and small mammals within the crop:

(a) Invertebrate families caught in pitfalls, pan traps and by sweep netting were examined in relation to feeding ecology of birds and small mammals

(b) Vegetation surveys were conducted in order to identify percentage cover of non-crop vegetation.

Aim 3. To define the crop characteristics (age / height / density / canopy shading / size of plot) that may influence biodiversity within it:

(a) Percentage cover, height of the crop and canopy shading were recorded at increasing distances into the crop

(b) Crop characteristics were related to the abundance and diversity of the birds and small mammals present using statistical analysis.

1.8 Field sites

1.8.1 Llysdinam, Powys (LL)

This field site was located at the Cardiff University field centre near Newbridge-on-Wye in the Brecknock division of Powys (Ordnance Survey grid reference: SO003581) at an elevation of approximately 200 m. The field was divided between *Miscanthus* and *Phalaris* crops, each covering an area of around 0.25 ha which were planted in 2004. Biomass was mown and baled in spring and no weed control or fertilizers were used for the duration of this study. A naturally vegetated headland of between 2 m and 6 m separated the crops from a mature unmanaged hedge on one side, a wire fence on another side and mature trees forming a woodland around the remaining two sides (Figure 1.4). Adjoining fields contained experimental short rotation coppice willow plots and also permanent pasture grazed by sheep, cattle and geese. One of the adjacent livestock-grazed fields was used as a comparison site.

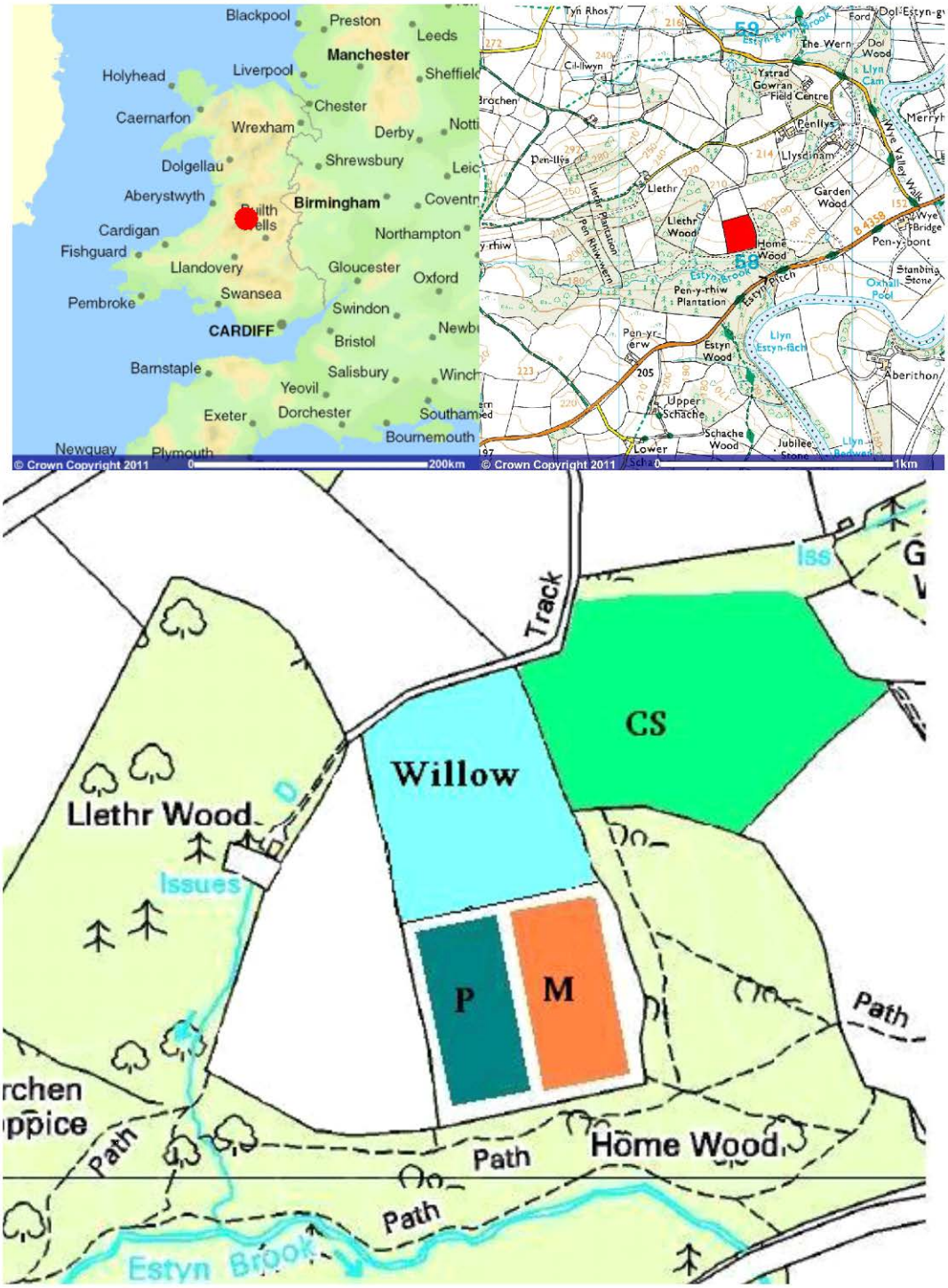

Figure 1.4 Maps showing the location of the field site and crops at LL. Key: M = *Miscanthus*, P = *Phalaris* and CS = comparison site. © Crown Copyright/database right 2011. An Ordnance Survey/ Edina Digimap supplied service.

1.8.2 Narberth, Pembrokeshire (N)

This study site was located close to the A40 near Slebech, Narberth in Pembrokeshire (Ordnance Survey grid reference: SN038147) at an elevation of approximately 75 m. Prior to rhizomes being planted in 2005, the ground was sprayed with broad-spectrum herbicide, ploughed and sewage sludge was applied. There was approximately 1 ha planted with *Phalaris* and 2 ha planted with *Miscanthus* (M1) and a small corner of *Arundo donax* in the *Miscanthus* plot (Figure 1.2). A further plot of *Miscanthus* was planted in the same field in 2006 (M2) and this was only used in the second year of surveys. Neither crop was treated with herbicide in 2008 or 2009 due to good canopy cover reducing weeds to an acceptable level. Biomass from this site was harvested once annually in spring and was destined for combustion at the nearby Bluestone Holiday Village in order to heat the sports club and administration offices. Adjoining fields either contained *Miscanthus* or were part of an arable rotation. The comparison plot for this site in the first year was a small field of rough, grassland set-aside of approximately 0.5 ha. In the second year of the project, comparison plots comprised a field of maize *Zea mays* on the other side of the track from M2, and a field adjoining the north hedge of the biomass crop field in which a neighbouring farmer grew spring barley *Hordeum vulgare*, following grazing by livestock during the winter.

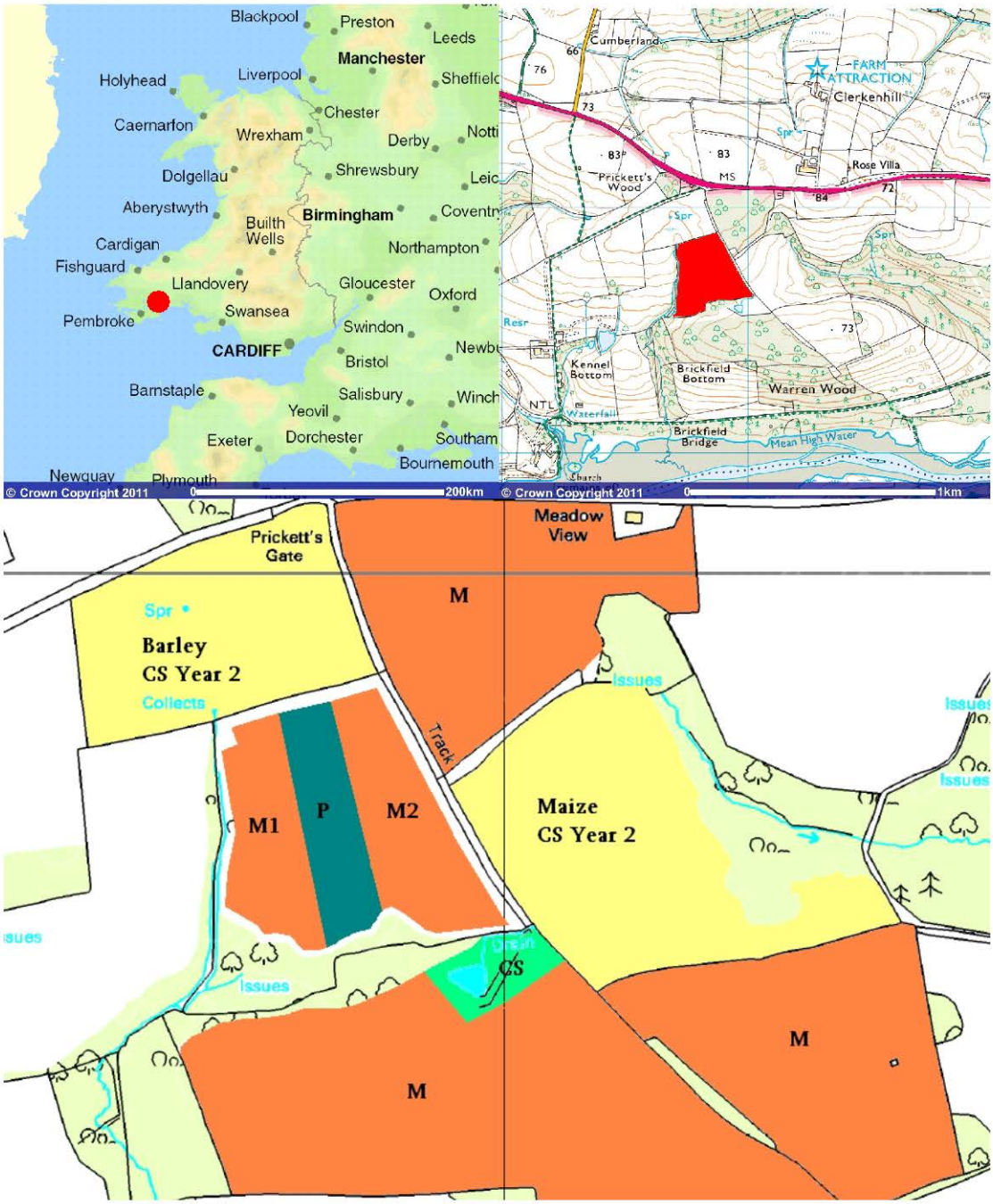

Figure 1.5 Maps showing the location of the field site and crops at N. Key: M = *Miscanthus*, P = *Phalaris* and CS = comparison site. M1 was used in the first year, M2 added for the second year. © Crown Copyright/database right 2011. An Ordnance Survey/ Edina Digimap supplied service.

1.8.3 Pwllpeiran, Ceredigion (PP)

The Llwynprenteg site is part of the ADAS Pwllpeiran experimental farm in Ceredigion. It was situated in the Ystwyth valley near Llanafan (OS reference Field 1: SN687715; Field 2: SN688716) at an elevation of approximately 100 m. The site consisted of two fields: Field 1 (PP1) was split between *Phalaris* (0.37 ha) and *Miscanthus* (0.27 ha), with a narrow strip of *Arundo* in between the two crops (Figure 1.3). This field was planted in 2004 and all crops were mown and baled in spring. An experimental trial of different slurry applications was undertaken by ADAS. No herbicide was applied in 2008/2009 season. Field 2 (PP2) had 2 ha of *Phalaris* sown in 2006 and the bottom half of it sloped steeply down to the river. This field was also part of the ADAS slurry trials and due to an invasion of broad leaved dock, the broad spectrum herbicide Glyphosate (N-(phosphonomethyl) glycine) was applied in spring 2008 and 2009. As part of the European Union "Field to Farmer" scheme (a scheme to advance energy crop research to a commercial farm scale in Objective 1 areas of Wales) this crop was cut in August then dried and baled for livestock bedding trials. In 2007, 2008 and 2009, the aftermath was grazed by sheep during tupping for one month in October/November. Both fields were surrounded by mature hedges containing some trees and there was a naturally vegetated 4 m headland between the hedges and the crops as well as between the different crops in Field 1. The comparison site was a sheep-grazed permanent pasture in an adjoining field.

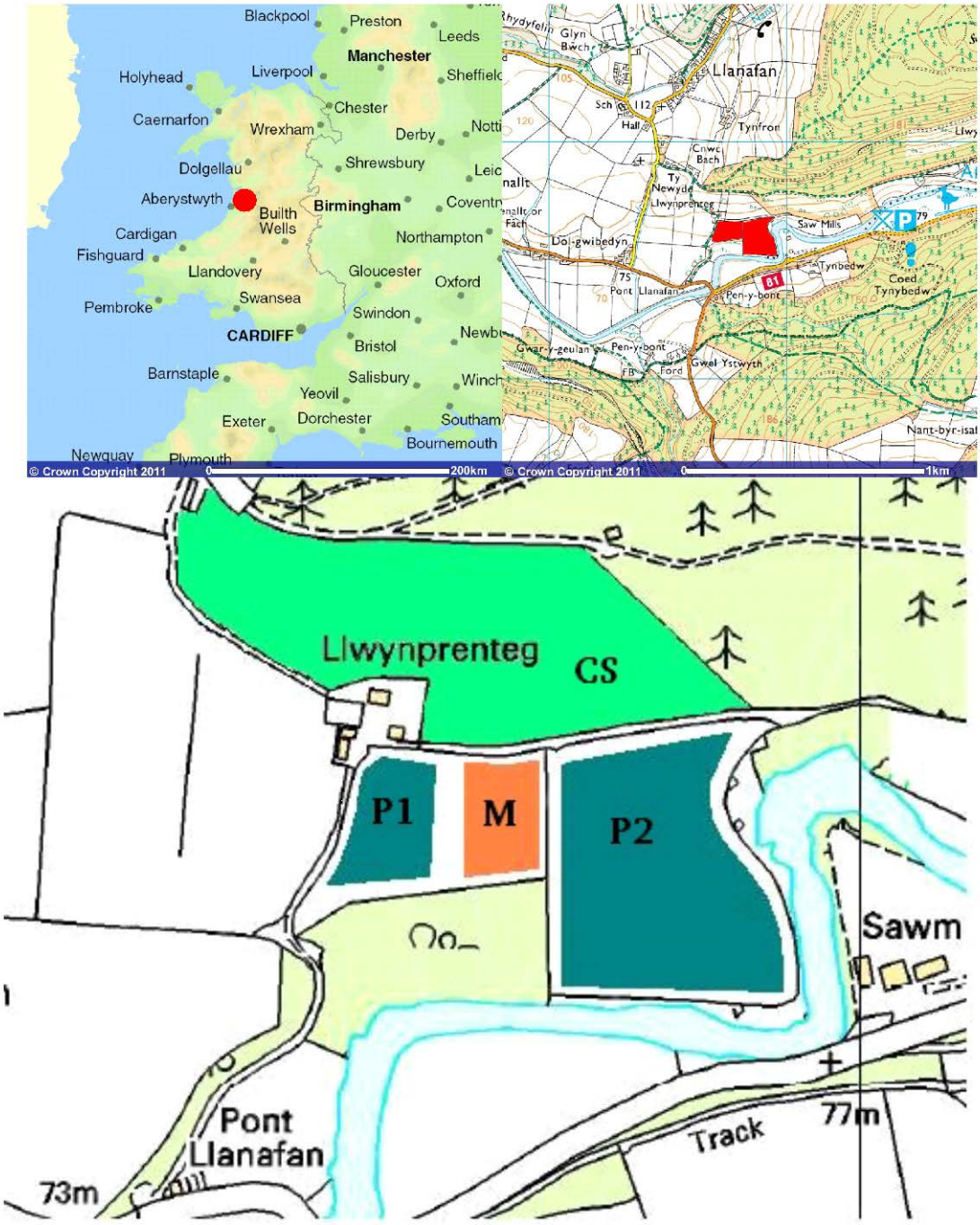

Figure 1.3 Maps showing the location of the field site and crops at PP. Key: M = *Miscanthus*, P = *Phalaris* and CS = comparison site. See text for explanation of P1 and P2. © Crown Copyright/database right 2011. An Ordnance Survey/ Edina Digimap supplied service.

1.8.4 Hinton Manor, Herefordshire (HM)

This site was located between the villages of Eardisland and Shobdon in Herefordshire (Ordnance Survey grid reference: SO407591) at an elevation of approximately 100 m, near the river Arrow. In total, there were over 36 ha of *Miscanthus* at the Manor, all of which was grown in rotations of 3 years before the rhizomes were harvested and sold. *Miscanthus* biomass was mown and harvested in late winter / spring and supplied to Bluestone. Fields in which the rhizomes had been harvested were left to regenerate from the pieces of rhizome not collected by the machinery. For this study, the field known as Red Bank (3.88 ha), which was planted in 2005 was surveyed (Figure 1.4). It was surrounded by a naturally vegetated headland of 2 m and managed hedgerows containing some mature trees. There were also three mature oak trees in the middle of the field. Adjoining fields contained *Miscanthus* and blackcurrants, and cereals on the neighbouring farm. Comparison sites were a blackcurrant *Ribes nigrum* field and a small set-aside grass field. This site was used in the first year only as the rhizomes were harvested in mid December 2008 without prior notice.

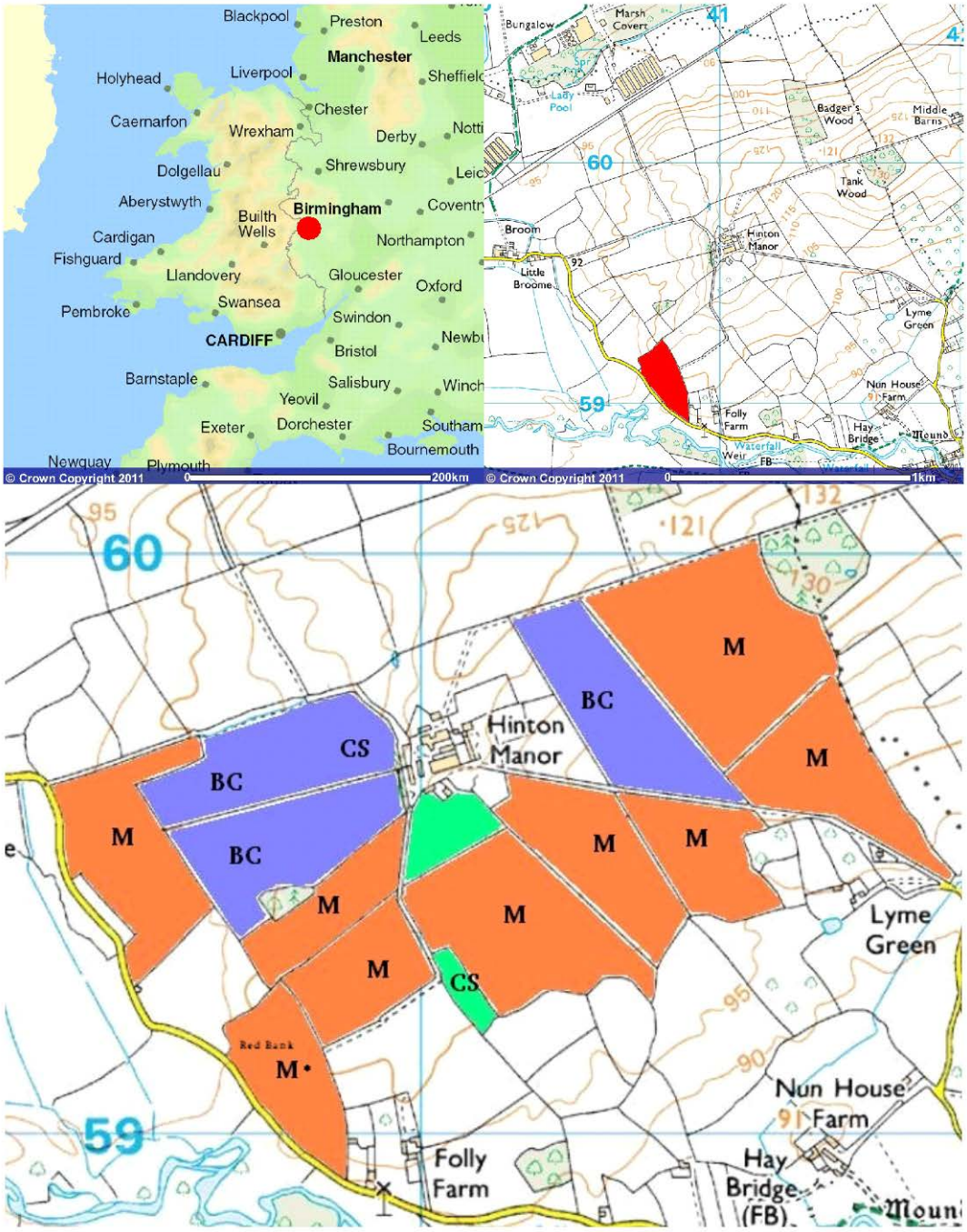

Figure 1.4 Maps showing the location of the field site and crops at HM. Key: M = *Miscanthus*, BC = blackcurrant fields, CS = set-aside grass comparison site. Red Bank M* = study field. © Crown Copyright/database right 2011. An Ordnance Survey/ Edina Digimap supplied service.

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CHAPTER 2

NON-CROP VEGETATION AND INVERTEBRATES AS FOOD RESOURCES IN BIOMASS GRASS CROPS

Abstract

It is thought that the presence of the two biomass grass crops *Miscanthus* x *giganteus* and *Phalaris arundinacea* may be deleterious to native biodiversity. Surveys of both non-crop vegetation and invertebrates were carried out every four months over the period of one year at four sites across mid and west Wales and Herefordshire. The aim was to identify non-crop vegetation and invertebrates present within the biomass crops and to relate these to potential food resources for birds and small mammals as well as other ecological services they may perform.

Phalaris, the comparison plots and the headlands contained a higher overall abundance of invertebrates than the *Miscanthus*. The highest number of invertebrate families was found in the headlands. Invertebrate catch across all habitats was dominated by individuals from the order Diptera. Abundance of invertebrates was strongly influenced by the month of sampling, with the maximum recorded in August. Invertebrates were evenly distributed throughout the crops, and within the plots, no edge effect was evident. Within the *Miscanthus* crops, the use of sticky traps revealed a significant difference in height distribution of three hymenopteran families.

Phalaris contained a greater abundance of non-crop plant species and a greater proportion of weed ground cover than *Miscanthus*, and the headlands contained the highest number of plant species. *Phalaris* crops contained a greater proportion of crop cover than *Miscanthus*, for which crop litter comprised a higher percentage of ground cover than the crop itself. Both crops caused significant shading at ground level, with maximum shading occurring in October.

The diversity of non-crop vegetation found within the biomass grass crops (but particularly the *Phalaris*), has the potential to support many invertebrates that are important as food resources to taxa at higher trophic levels.

2.1 Introduction

Within an agroecosystem, the importance of plant and invertebrate taxa within the food web and those responsible for a wide range of ecosystem services cannot be ignored. This chapter will consider the "weeds" (i.e. the non-crop vegetation) and invertebrates, predominantly in relation to their trophic roles as either consumers or prey, although the wider benefits of their presence will also be explored.

Plants play an important role in many different respects. As primary producers, they provide resources that are central to the function of trophic webs, from sustaining phytophagous invertebrates grazing on leaves and stems, pollinating insects collecting nectar and pollen, to seeds and fruits being consumed by small mammals and birds (Marshall *et al*. 2003). It would be impossible to explore all trophic relationships based on weeds within an agro-ecosystem, but this chapter will focus on the ecological role of invertebrate taxa beneficial to key taxa at higher trophic levels.

2.1.1 Weeds and invertebrates

Different species of agricultural weeds are vital in order for many invertebrates to complete their life cycles, and also create architectural heterogeneity and shelter within the agricultural landscape (Marshall *et al*. 2003). A heterogeneous weed assemblage within a landscape can therefore support a diversity of different taxa, and this in turn ensures provision of a range of ecosystem services (Hyvönen & Huusela-Veistola 2008).

Meek *et al*. (2002) reported that both the nectar-feeding and pollinating invertebrates tended to be found in areas of sown wild flowers rather than grasses, although there was also a preference for floristically diverse field margins in comparison with arable crops. The presence of wild flowers is also important for hymenopteran parasitoids, which require pollen and nectar as a food source whilst

seeking out prey to parasitize (Langer 2001). Altieri (1999) lists the weed families Umbelliferae, Leguminosae and Compositae as being important resources for, and reservoirs of beneficial arthropods. As such, many feedback mechanisms may exist as a result of reduced herbivory due to the influence of invertebrate predators and parasitoids. If natural enemy populations can be enhanced by prudent management to include floristically diverse habitats on farmland, then biological pest control is just one of the many benefits arising in terms of ecosystem services.

The abundance of pollinating insects in agricultural crops can be negatively affected by the distance to natural habitat. However, where weed patches were present within a sunflower crop, abundance of pollinators was double that of plots where no weeds were present (Carvalheiro *et al.* 2011). It was thought that these islands of weed flower resources allowed pollinators to penetrate further into the agricultural landscape and were therefore of major importance. Furthermore, the authors reported higher insect diversity in diverse sunflower plots and this in turn resulted in more movement around the crop by the honey bee *Apis mellifera* than where other pollinators did not occur. Although the presence of pollinators is generally accepted to be a good thing, there has been speculation that their presence may also enhance the reproduction of undesirable weed populations. A study in New Zealand concluded that the impact of the honey bee on invasive weed reproduction in environmentally sensitive areas was minimal due to the high proportion of the weeds concerned being wind-pollinated and that the fears regarding bees facilitating the pollination of invasive weeds at the expense of native species were unfounded (Butz Huryn & Moller 1995). Conversely, an Australian study showed that the primary pollinator of an alien invasive weed species (hairy fogfruit *Phyla canescens*) was the honey bee, which was responsible for the potential production of up to half a million seeds per hectare (Gross *et al.* 2010), suggesting that these are variable and potentially complex, species-specific relationships.

One of the ways in which the activities of herbivorous invertebrates and vertebrates may strongly influence weed community composition, is through a reduced seed bank as a result of the consumption of weed seeds by herbivores. Potential predators of seeds include small mammals, birds, ants, carabid beetles and slugs (Baraibar *et al*. 2011; Ichihara *et al*. 2011; Navntoft *et al*. 2009; Holmes & Froud-Williams 2005; Westerman *et al*. 2003). Increased diversity of carabid beetles was positively associated with seed predation within crop and non-crop habitats, even though beetle assemblages varied between the two areas (Gaines & Gratton 2010). Although some species of carabid beetle are totally phytophagous, the polyphagous species appear to rely on weed seed resources early in the season, switching to prey items later as they become more abundant (Mauchline *et al*. 2005). In perennial forage crops, increasing levels of weed seed predation by both vertebrate and invertebrate predators were linked to increasing crop vegetation cover (Meiss *et al*. 2010), and in no-tillage systems higher densities of seed-predating carabids were present than in conventional or organic systems (Menalled *et al*. 2007). Earthworms (e.g. *Lumbricus* spp.) in addition to ingesting leaf litter, commonly ingest large quantities of small weed seeds, and although the nutritional value of the seeds to the earthworm is unclear, they are thought to benefit earthworm populations (Franke *et al*. 2009). An abundant weed seed bank in the soil may therefore indirectly have a positive influence on soil structure and quality, mediated through earthworm activity. Although weed seeds could provide additional resources, allowing polyphagous pest species such as slugs to persist, their availability may also reduce the frequency of attack on crop plants by the slugs (Franke *et al*. 2009).

2.1.2 Weeds and vertebrates

Hyvönen & Huusela-Veistola (2008) reported that annual weeds were of great importance to farmland birds, due to the abundance of small seeds produced, and Holland *et al*. (2006) agreed that arable weeds formed a significant proportion of

the diet of most birds. The annual weeds providing much of this important seed resource rely on regular tillage and may not be as prolific in undisturbed leys or field margins, where grasses rapidly dominate (Robinson & Sutherland 1999). Grassland weed seeds form an important part of the diet of the goldfinch *Carduelis carduelis* and linnet *Carduelis cannabina*, despite agricultural grassland habitats tending to comprise simplified, homogenous grass swards (Holland *et al*. 2006). Where herbicides are in use on lowland grassland, the presence of granivorous birds is reduced (Buckingham *et al*. 2006), presumably through the resulting reduction in seed availability.

A review by Holland *et al*. (2006) reported certain plant families that were considered to be of particular importance for farmland birds, in order of significance: Poaceae, Polygonaceae, Caryophyllaceae, Cruciferae, Compositae, Chenopodiaceae and Labiatae. Despite some other plant species being recorded in high abundance, they were not present in the diet of farmland birds (common poppy *Papaver rhoeas*, cleavers *Galium aparine*, ivyleaved speedwell *Veronica hederifolia*, mayweeds *Matricaria* spp, wild oats *Avena fatua*, sterile brome grass *Anisantha sterilis*, couch *Elymus repens* and blackgrass *Alopecurus myosuroides*), suggesting that the abundance of different taxa does not necessarily equate to their value as food items (Holland *et al*. 2006). Wilson *et al*. (1999) also looked at important genera in the diet of farmland granivorous birds, listing cereals (*Triticum* spp.*, Hordeum* spp. and *Avena* spp.), *Polygonum* spp. (knotgrasses and persicarias), *Stellaria* spp. (chickweeds and stitchworts), *Chenopodium* spp. (goosefoots) and members of the Asteraceae (dandelions, thistles etc).

Mauchline *et al*. (2005) reported that when mesh was used to exclude birds from weed-seed predation experiments in spring barley, there was a minimal effect on numbers of seeds removed. However, when mesh size was reduced to also exclude small mammals, a significantly lower number of seeds were taken, particularly of fat hen *Chenopodium album* and common knotgrass *Polygonum aviculare*. Similar

results were obtained by Kollmann & Bassin (2001), whereby small mammals and slugs were the dominant seed predators in wildflower strips, with avian and insect seed predators having a negligible effect on seed abundance. In contrast, bird exclusion nets in willow *Salix* spp. short rotation coppice resulted in minimal seed removal compared with areas to which birds had full access (Fry & Slater 2011). The authors concluded that in this habitat, (where seeds were produced naturally by the existing weeds rather than being provided in dishes by researchers), birds were the dominant seed predators rather than small mammals, which were not excluded. Within otherwise homogenous cereal crops, weed patches containing favoured seeds were visited more often by wood mice *Apodemus sylvaticus* than other areas within the crop (Tew *et al.* 2000).

2.1.3 Invertebrates as a food resource

Many bird species rely on invertebrates as a food resource – either as their dominant prey type, or as chick food for otherwise granivorous birds during the breeding season (Hart *et al.* 2006; Wilson *et al.* 1999). Vegetation structure and management can strongly influence foraging decisions by birds, and although invertebrate resources may be more abundant in taller swards, these tend to be avoided in favour of shorter swards or bare ground, thought to be due to increased predation risk (Atkinson *et al.* 2004). The authors also reported that bird species favouring soil invertebrates preferred the shorter grass swards that are typical of intensive management and were therefore less likely to be negatively influenced by modern farming techniques than species reliant on foliar invertebrates.

In terms of invertebrate families comprising an important element of the diet of 26 farmland granivorous bird species, the following are listed by Wilson *et al.* (1999): grasshoppers (Orthoptera: Acrididae), sawflies (Hymenoptera: Symphyta), spiders (Arachnida: Araneae), leaf-beetles and weevils (Coleoptera: Chrysomelidae and Curculionidae), caterpillars (Lepidoptera), aphids (Hemiptera) and crane-flies

(Diptera: Tipulidae). Holland *et al*. (2006) studied invertebrate taxa important during both the breeding season and non-breeding season. They reported that during the breeding season the following families were important for at least four bird species: Aphididae (Hemiptera), Carabidae (Coleoptera), Chrysomelidae (Coleoptera), Curculionidae (Coleoptera), Elateridae (Coleoptera), Formicidae (Hymenoptera), Scarabeidae (Coleoptera), Staphylinidae (Coleoptera), Tenthredinidae (Hymenoptera) and Tipulidae (Diptera), whilst Curculionidae (Coleoptera) and Lumbricidae (Annelida) were important in the non-breeding season.

Small mammals also rely to varying degrees on invertebrate food. For the common shrew *Sorex araneus*, adult Coleoptera, insect larvae, Araneae, Opiliones and Isopoda comprise the majority or prey items year-round, with lumbricids and adult Diptera being of secondary importance (Churchfield 1982). The pygmy shrew *Sorex minutus* also takes Coleoptera, Araneae and Opiliones, but tends to prey on smaller, surface-active individuals, in contrast to the common shrew, which is more likely to pursue burrowing invertebrates (Pernetta 1976). Both of these shrews are widely found in habitats such as dense grassland where there is good vegetation cover (Churchfield & Searle 2008). The water shrew *Neomys fodiens*, although predominantly associated with freshwater streams, also forages away from water on terrestrial invertebrates. Prey items taken by the water shrew overlap with those in the diet of the common shrew, but also include millipedes (Diplopoda), centipedes (Chilopoda), molluscs and earthworms (Churchfield & Searle 2008). Invertebrates also feature in the diets of the omnivorous rodents. The wood mouse takes live caterpillars (Lepidoptera), centipedes, earthworms and coleopterans, as well as a larger range of dead or dying invertebrates (Flowerdew & Tattersall 2008). Although there has been little work on the diet of the harvest mouse *Micromys minutus* in the wild, they have been reported to actively pursue and consume both hard-bodied insects and soft-bodied Lepiodoptera in captivity (Trout & Harris

2008) and are also thought to consume pest prey such as aphids (Hemiptera) in cereal crops (Harris 1979). Green vegetation, seeds, fruits and mosses also form part of the diet (Trout & Harris 2008), but the relative importance of plants and invertebrates in the diet of wild harvest mice is unclear.

2.1.4 Management effects and agricultural intensification

Where agricultural practices have intensified, the abundance of invertebrates is generally reduced (Benton *et al.* 2002). In addition to agrochemical use, factors such as ploughing/tillage can have a significant effect on invertebrates, and increased soil microarthropod diversity is thought to be related more to minimum tillage systems than the pesticide regime in use (Cortet *et al.* 2002).

Although application of herbicides does not directly affect invertebrates, an indirect effect mediated by loss of resources provided by the weeds has been reported, with reductions seen in both invertebrates and granivorous birds where herbicides have been applied (Buckingham *et al.* 2006; Taylor *et al.* 2006; Boatman *et al.* 2004; Moreby & Southway 1999). Herbicide use was seen to change foraging patterns of the corn bunting *Emberiza calandra*, which preferred areas of low herbicide use (Brickle *et al.* 2000). Pesticide use was reported to be directly linked to a reduction in available invertebrate food for yellowhammer *Emberiza citrinella* chicks, with a consequent negative effect on nestling condition (Morris *et al.* 2005; Boatman *et al.* 2004). Most insecticides are non-specific in their action and also result in reductions in beneficial invertebrates such as predators and parasitoids, and thus they reduce the effectiveness of potential biological control of pest species (Geiger *et al.* 2010, Morris *et al.* 2005).

2.1.5 Agri-environment schemes

Although the purpose of field margins and boundaries was originally for stock control, shelter and demarcation of boundaries, their function has expanded over recent years to include biodiversity conservation measures. Marshall & Moonen (2002) propose potential roles that include the enhancement of natural enemy and pollinator populations, buffering agrochemical movement, conservation of soil and the promotion of diversity and ecological stability. The buffering of agrochemicals is usually achieved by leaving an unsprayed strip adjacent to the field margin. Although a 6 m unsprayed buffer zone around cereal crops did not prevent the arthropods within the zone succumbing to insecticide applications, recolonisation of the main field by invertebrates was more extensive where buffer zones had been created (Holland 1999).

It is recognised that having floristically diverse field margins can positively influence the diversity of other taxa. To this end, many agrienvironment prescriptions incorporate 'conservation headlands' or uncultivated and untreated field margins in both arable and pastoral systems (Vickery *et al.* 2009; Sheridan *et al.* 2008; Denys & Tscharntke 2002). In terms of the best ways to establish these margins, Sheridan *et al.* (2008) reported that reseeding with a mixed grass and flower mixture was the most successful. They found that natural regeneration alone allowed too many unwanted, competitive weeds to dominate, while withholding nutrients and fertiliser resulted in too slow a rate of change to the flora. Conversely, Meek *et al.* (2002) found that natural regeneration allowed rare arable weeds that did not grow in sown plots to persist.

The structure of the vegetation in a sown margin may influence the types of invertebrates that are supported within it: Woodcock *et al.* (2005) reported that margins sown with fine grasses were associated with a smaller and less diverse beetle community than margins sown with tussock-forming grass mixes. An age-

effect was also reported by Denys & Tscharntke (2002), whereby natural enemy abundance and predator-prey ratios were higher in margins that had been established for a longer time period, and where tussocks had formed.

2.1.6 Weed and arthropod diversity in biomass crops

Miscanthus x *giganteus* and *Phalaris arundinacea* (hereafter referred to as *Miscanthus* and *Phalaris*) crops in the first three years after establishment were surveyed by Semere & Slater (2007). They reported higher abundance and diversity of families of Diptera, Hymenoptera, Hemiptera and arboreal Coleoptera in the *Miscanthus* fields (and their margins), which had particularly high weed content, at between 40% and 96% cover. However, the field margins tended to have a higher number of invertebrate families than the cropped areas, and as the two areas were combined in the analysis, it is less clear what the invertebrate response to the *Miscanthus* crops was. The dominant invertebrate families found within the cropped areas and margins by Semere & Slater (2007) are shown in Table 2.1.

Although their study was on crops that had not necessarily established well in their first few years, Semere & Slater (2007) concluded that the non-crop vegetation was of great importance in supporting invertebrate diversity, but was an effect that may be reduced in more mature crops with fewer weeds.

Bellamy *et al.* (2009) compared weed and invertebrate food resources for birds between paired fields of winter wheat, and *Miscanthus* crops that had been planted between one and four years prior to the study. They found that there were very few significant differences between the wheat and biomass crop in terms of invertebrate distribution in winter, even though the abundance and biomass of earthworms (Annelida) was greater in *Miscanthus*. They suggested that this could have been due to variability between soil quality in the different crops and the age of the *Miscanthus* crops at the different sites.

Table 2.1 The dominant invertebrate families recorded in biomass grass crops and their margins, as reported by Semere & Slater (2007).

Order	Cropped areas	Headlands
Diptera	Bibionidae	Sciaridae
	Phoridae	Anthomyzidae
	Sciaridae	Chloropidae
	Anthomyzidae	Chironomidae
	Chironomidae	Bibionidae
	Chloropidae	Lonchopteridae
Hymenoptera	Pteromalidae	Pteromalidae
	Braconidae	Platygastridae
Hemiptera: Heteroptera	Miridae	Miridae
	Anthocoridae	Anthocoridae
Hemiptera: Homoptera	Aphididae	Aphididae
		Cercopidae
		Cicadellidae
Coleoptera (arboreal)	Chrysomelidae	Chrysomelidae
	Cantharidae	Coccinellidae
	Coccinellidae	Curculionidae
		Phalacridae

During the bird breeding season, a significantly greater abundance of invertebrates was recorded on non-crop vegetation within the *Miscanthus* than on either the *Miscanthus* plants or the wheat crop. The only exceptions to this were the Coleoptera, which were more abundant in the wheat crops, but only in the sweep net samples, not in the pitfall traps. In all cases, non-crop vegetation comprised significantly greater percentage cover in *Miscanthus* fields, which had a mean crop cover of 67% ±4% compared with 91% ±1.2% in wheat (Bellamy *et al*. 2009).

Switchgrass *Panicum virgatum* is a prairie grass native to North America, of which certain cultivars are grown commercially for biomass. Where switchgrass and natural prairie in the USA were managed non-intensively, there was a positive influence on the abundance of beneficial insects in comparison with annual crops such as maize (Gardiner *et al*. 2010). However, it was thought that if these crops were grown intensively for biofuel production, the same positive effect may not exist.

2.1.7 Assessing abundance

The presence of weeds (or non-crop vegetation) and the composition of the assemblage present in an agricultural landscape is entirely dependent on management practices such as herbicide use, season of sowing or grazing practices (Hawes *et al*. 2009). However, assessment of weed diversity and abundance is a relatively simple task, performed by assessing ground cover of individual species (e.g. Bellamy *et al*. 2009).

Conversely, assessment of an invertebrate community is a far more complex task. There are many well established capture methods, but no one technique is suitable for the whole range of aerial and epigeal invertebrates. In tropical rainforest, Noyes (1989) reported varying levels of trapping success within different areas of the forest, despite using the same trapping techniques, thought to be due to vegetation structural differences. He also found that certain techniques (such as pan trapping) were more effective for certain groups of invertebrates than other methods.

In addition to the spatial differences in habitat use by invertebrates, seasonal and other temporal differences may exist. A study on spiders in citrus orchards revealed significantly different results between nocturnal and diurnal samples which may have led to misinterpretation of a predatory spider community composition (Green 1999). Therefore, all these factors need to be taken into account when planning survey methodology.

Explanations of the commonly used invertebrate trapping techniques are outlined below.

Pitfall trapping

This involves sinking a plastic container or funnel into the soil, with the top of the container level with the soil surface. Invertebrates fall into the container and

cannot escape. A killing agent is sometimes used, otherwise the animals are left alive in the trap, which can increase the chance of predation within it. Traps containing a killing agent of propylene glycol or ethylene glycol captured a higher diversity of invertebrates than were caught in traps without a killing agent, attributed to reduced levels of predation due to the killing agent (Weeks & McIntyre 1997). Some traps are placed within a fenced area to increase the likelihood of taxa within that area encountering the trap, whilst others are left unfenced. These different types of pitfall trap may induce bias into the types of taxa caught. The use of unfenced traps in meadows and cereal fields resulted in greater catches of carabid (ground) beetles and fewer staphylinid (rove) beetles than those found in enclosed fenced traps (Mommertz *et al*. 1996). In the same study, a relationship between arthropod body size and trap type was demonstrated, whereby the larger the body size of the arthropod, the more likely it was to be found in unfenced traps. The converse applied to smaller species and fenced traps. Further factors to be considered when using pitfall traps are that rather than just catching invertebrates travelling over the soil surface, species normally dwelling within the vegetation that drop to the ground when disturbed may fall into the traps (Standen 2000). In addition to 'passively' trapping invertebrate taxa that happen to encounter the trap, the presence of dead or dying trapped individuals may also actively attract carrion consumers to the traps (Standen 2000), which may skew the proportions of these types of taxa within a pitfall trap. In comparison with D-vac sampling, pitfall traps were more effective in catching Lycosidae (Araneae; Mommertz *et al*. 1996) and Coleoptera (Standen 2000). There is some evidence of species-specific behavioural responses to pitfall traps: Topping (1993) reported a low capture rate for liniphyiid spiders, which required from 16 to 57 encounters with the pitfall traps before becoming trapped. Results from pitfall trapping for spiders may also differ from absolute density sampling. This is thought to be due to different activity levels relating to mate-searching and hunting which are likely to vary between species and sexes (Topping & Sutherland 1992). This is

in contrast to results reported by Churchill & Arthur (1999) who recorded 94% of spider species present using pitfall traps in comparison with 25% and 41% for sweep net and direct searching techniques respectively. Both Topping & Sutherland (1992) and Meek *et al.* (2002) urge caution in how pitfall catch data are interpreted due to the limitations of the technique, and the possibility of trapping results being highly influenced by the extant vegetation structure as well as temporal changes in invertebrate activity.

Vacuum sampling

D-vac and Vortis sampling methods make use of strong suction to remove invertebrates from the soil and vegetation surface into a collecting vessel. The suction head, usually a standard diameter is placed quickly onto the vegetation and any invertebrates captured are diverted into a specimen container. Having a known diameter of sampling area allows estimates to be made of invertebrate abundance per unit area. In a study in cereal fields and meadows, fewer taxa overall were caught by D-vac sampling than by the use of pitfall traps (Mommertz et al 1996). This is thought to be due to the fact that heavier arthropods and those able to burrow into the soil escape the suction current. However, vacuum sampling has been shown to be the most effective technique for Hemiptera, both in terms of species richness and abundance in understorey vegetation (Moir *et al.* 2005). Limitations to the technique include a tendency for water to be sucked from wet ground into the apparatus and also the large volume of plant material collected where there is abundant litter (Drake *et al.* 2007).

Swish-net / sweep net

These techniques, which use wide sweeps of a fine mesh net are designed to catch aerial insects and those on canopy vegetation. The Diptera are best sampled by these methods (Standen 2000) and sweep netting was also determined to be the most effective in terms of sampling effort for Orthoptera (Nagy *et al.* 2007).

Limitations to sweep netting include reduced effectiveness in strong winds and on wet vegetation, and the possibility that large predatory insects may prey on other individuals in the catch (Drake *et al.* 2007).

Pan traps

These shallow containers of water are usually painted yellow, in order to attract and capture pollinating and phytophagous insects, which settle on and become trapped in the water. However, what may seem to the human eye to be similar shades of yellow may be perceived differently by the insect eye, and could influence the effectiveness of the traps (Duelli *et al.* 1999). As the traps are shallow, there is a risk of loss of liquid through evaporation in hot weather, or from flooding and overflowing in wet weather (Drake *et al.* 2007).

Sticky traps

These are commonly used in both horticulture and agriculture in order to either assess populations of beneficial predatory insects (Parajulee *et al.* 2003), or to trap and remove insect pests. They are particularly effective for trapping Hymenoptera, Thysanoptera, Hemiptera, Diptera, Araneae and Coleoptera (Thomson *et al.* 2004). Factors influencing the types of insect caught on sticky traps include trap colour and orientation. Shades of yellow have been shown to be more successful than other trap colours for many different taxa (Parajulee & Slosser 2003; Mensah 1996; Muirhead-Thomson 1991), but the best orientation angle varies between taxa (Muirhead-Thomson 1991). A study on a salt marsh recorded higher numbers of hoverflies Syrphidae and thrips Thripidae on blue traps (Wyatt Hoback *et al.* 1999). In parasitoid wasps of the Trichogramma family, females preferred white traps, whereas males were found more abundantly on yellow traps (Romeis *et al.* 1998). Although yellow sticky traps have been used successfully in combination with other collection techniques for Hemiptera, it was found that after a period of 600

minutes, an asymptote of sampled species abundance was reached and no further species were caught (Moir *et al.* 2005).

In a study where pitfall traps or a combination of swish-netting and D-vac were used, many arthropod families were found mainly by one or the other method. Some species were solely found by one method, indicating that a range of sampling techniques should be used to account for all taxa present (Standen 2000). This also applied to other techniques: for Hemiptera, an optimal combination was vacuum sampling, sticky traps and beating of vegetation (in order to dislodge invertebrates from the plant, which are then caught on a sheet below the plant), (Moir *et al.* 2005).

Assessing the biodiversity of a habitat can be a very time and labour-intensive exercise, which requires specific expertise in identifying taxa. Potential shortcuts allowing researchers to reach the same conclusions will always be an attractive option. Biaggini *et al.* (2007) used order level to define invertebrate abundance on different agricultural habitats – a measure that was as effective as using only differences in carabid beetle species (rather than a broader range of taxa) to quantify abundance.

2.1.8 Aims

The aim of this chapter was to assess the abundance of non-crop vegetation and invertebrates in biomass grass crops and their headlands and to relate this to their role as potential food resources for birds and small mammals, the ecosystem services they provide and overall biodiversity. It is hypothesised that the combination of crop structure and management involving minimal disturbance will increase weed and invertebrate abundance and diversity within the biomass crop fields.

2.2 Materials and methods

2.2.1 Invertebrates

Biomass crops of *Miscanthus* x *giganteus* and *Phalaris arundinacea*, their margins and comparison "control" plots at four sites in Wales and Herefordshire (as described in Chapter 1) were surveyed. Survey transects at distances of 10 m, 20 m and 50 m (where plot size allowed) from the crop edge were established. A transect was also established in the headlands, mid-way between the hedge / field boundary and the edge of the crop. A further transect within the comparison plots at each site was also surveyed. Trapping for invertebrates was carried out during the April, August and December survey periods in the first year of fieldwork (2008), in order to sample at three distinct crop stages (stubble, tall vegetative growth and senesced standing material). A range of trapping techniques was employed, in order to maximise the catch of both epigeal and aerial invertebrates.

Pitfall traps

A garden bulb planter was used to extract a core of soil, in order to form a hole deep enough to contain plastic vending cups of 7 cm diameter and 8 cm depth, so that the top of a cup placed in the hole remained flush with the soil surface. A small piece of 2.0 x 2.5 cm diameter rigid plastic mesh was placed in the cup to act as an escape ladder for small mammals, after establishing with preliminary observations that large Lycosid spiders and Carabid beetles were unable to escape from the trap by climbing it. 40 ml of 50% ethylene glycol solution was placed in the cup and a 10 cm^2 square of wire mesh was elevated 3-4 cm above the top of the trap using wooden pegs, in an attempt to protect the contents from disturbance or ingestion by vertebrates. Three traps were laid 2 m apart at each transect within the crops, headlands and comparison sites.

In preliminary trials, the pitfall traps were left in position for seven days, but the quantity of slugs trapped resulted in all other specimens becoming coated in slime

and therefore difficult to identify. Some deterioration and disintegration of specimens was also seen and it was evident that seven days was too long a period for the trap to be left in the field. The traps were therefore only left in position for 24 hours, after which the contents were filtered using permeable tissue ("nappy liner", Boots) which was fine enough to conserve all the smallest invertebrates within the catch when the liquid portion was removed. Slugs and worms were removed and discarded, and the remainder of the catch was preserved in 70% alcohol.

Vortis suction sampling.

A Vortis Insect Suction Sampler (Burkard Manufacturing Co. Ltd. Rickmansworth, Hertfordshire, UK) with a sampling diameter of 16 cm was operated for 10 seconds each at three positions along each transect, combined to give one 30 second sample per transect. One 30 second sample was taken in each crop and headland transect and three samples were taken from the comparison plots. Each sampling position was at least 2 m away from the last and the suction nozzle was placed quickly over the vegetation onto the ground to minimize escape by spiders and beetles. Captured specimens were killed immediately using ethyl acetate in order to prevent predation within the sample pot, then preserved in 70% alcohol on return to the laboratory.

Several problems were encountered when using the Vortis Sampler for sample collection and it was soon discontinued. In particular, it could not be used when any moisture was present on the soil surface, which resulted in a succession of missed samples after rainy periods. The samples that were collected were eventually discarded, as the quantity of vegetation debris and the deterioration of the specimens that occurred prior to preservation made identification and counts too time-consuming and unreliable to be used in the analysis.

Yellow pan traps

Clear plastic oval disposable salad containers measuring 12 cm x 16 cm x 4 cm were painted yellow by spraying the underside with Plasti-Kote Projekt Paint Fast Dry Enamel in Buttercup Yellow (#113S). A dome of 2.5 cm diameter wire mesh was attached over the top of the trap to prevent birds consuming the contents and this was suspended from a 1 m cane pushed into the ground at an angle. This resulted in the trap being positioned slightly above the canopy during the very early stages of crop growth, but at or below canopy level as the biomass crops became taller. Direct contact with the ground and vegetation was avoided where possible to reduce invasion by slugs. One trap was set in each transect and headland and three were placed in the comparison plot at each site. Once set, 60 ml of yellow 50% ethylene glycol solution was placed in the trap, which was then left in position for 7 days. After this time, contents of the trap were filtered through a piece of nappy liner and preserved in 70% alcohol.

Sweep netting

During calm, dry weather, a sample comprising 10 sweeps were made through the top of the vegetation at approximately 50 cm intervals whilst walking slowly forwards. The catch was then collected from the net using a pooter and the specimens were killed by inserting twist of tissue paper soaked with a drop of ethyl acetate into the pot. One sample of 10 sweeps was taken at each transect and three samples were collected in the comparison plots. In the later stages of *Miscanthus* crop growth, when it was well above head-height, it became more difficult to include the top of the canopy in the net sweeps, so the technique had to be slightly modified (with higher sweeps) in order to maintain an equivalent sampling effort to that in the *Phalaris*.

Sticky traps

Initial trapping sessions using 9 cm x 25 cm yellow sticky traps (Oeceos Ltd) were conducted during October 2007 at each field site. Traps were suspended from tall bamboo canes at three different heights in the *Miscanthus* in order to represent the top, middle and bottom part of the canopy, whilst avoiding contact with the ground and the vegetation itself. Two heights only were used in *Phalaris* to reflect the shorter crop. After a period of 5 days the traps were collected, placed in a freezer to kill the specimens and then placed under a binocular dissecting microscope for identification and counting. Where possible, individuals were identified to family level, but the inability to move the specimens off the trap made it impossible to identify Diptera beyond order level. The quality of the trapped invertebrates also varied – during some trapping sessions it had rained copiously and some decomposition of the invertebrates was evident. It was also evident that slugs had invaded the traps and consumed many of the invertebrates on them, adding further difficulty to the accurate counting of those present. Although some spiders were found on the sticky traps, it was clear that the traps were biased towards flying invertebrates.

Despite this, it was felt that the sticky traps could give a useful indication of how the invertebrates within each taxon were distributed vertically, particularly in the *Miscanthus*, which was up to twice the height of *Phalaris*. Traps were therefore set out at the three height levels in the *Miscanthus* at all four sites, but for just 24 hours in the August 2008 sampling period as a one-off sample.

Butterflies

Any butterflies (Lepidoptera) noted within the crops and headlands whilst other survey work was being undertaken were recorded. These observations were used as anecdotal evidence of butterfly abundance and diversity in the different crops,

but as no timed searches were carried out, these results were not analysed statistically.

2.2.2 Identification and counts

Preserved invertebrate specimens were examined in water-filled petri dishes, under a binocular dissecting microscope. Identification to family level was performed where possible, using a range of paper and on-line keys (see Section 2.5.1 for full details) and counts for each family were recorded. Collembola were identified to morphotype only (Symphypleona or Arthropleona) and there were a few individuals from other orders that were not identified to family level (e.g. Opiliones, Mecoptera and Trichoptera). Identification of the pitfall specimens was performed by the author, but the pan trap and sweep net specimen counts were performed by a research assistant (M. Postles). During the counts of the pan trap and sweep net specimens, a record was also made of size ranges of the invertebrates (in the categories: <1 mm, 1-5 mm, 5-15 mm and >15 mm). Size range was not recorded for the pitfall specimens, but the families found within them have subsequently been categorised into more general size ranges.

Sticky traps were also examined under the binocular dissecting microscope. The original backing paper was lightly reapplied to the side resting on the microscope stage in order to prevent it sticking. Where families could be identified with confidence, these were recorded. For most Dipterans however, only a distinction between the sub-orders Brachycera and Nematocera of different sizes was possible due to the inability to remove the specimens from the sticky trap.

2.2.3 Data analysis

Presence and counts

Counts of the individual invertebrates of the different size classes trapped in pan traps and sweep nets were pooled in order to give a single count per family. Counts

from the pitfall traps were added to these, giving a count per family per transect, per visit from the combined trapping methods. These were the count data used in the subsequent statistical analyses.

For analyses of the size class data, counts of families of the same size class in the sweep net and pan trap samples were added together and these multi-species size class counts were used for statistical analysis.

When tested for normality of distribution, abundance and size data from the invertebrate surveys were found to have a non-Gaussian distribution. Generalised linear models (GLM) and non-parametric Kruskal-Wallis tests were used to test for differences in invertebrate distribution and size ranges between areas sampled, seasons and distance into the crops. Where significant results were shown using the Kruskal-Wallis test, post-hoc pairwise comparisons of mean ranks of all pairs of groups (adjusted for multiple comparisons as part of an overall Kruskal-Wallis test) were used to define where the differences lay

Diversity indices were calculated using the number of invertebrate families present in a habitat. No attempt was made to perform statistical analysis on the diversity scores: even with uniform sample sizes, the indices have unequal variances and measures such as ANOVA are therefore not appropriate (Rogers & Hsu 2001).

2.2.4 Vegetation

Crop height was recorded bi-monthly from April 2008 – December 2008 at five points along each biomass crop and headland transect. In the early stages of growth (where the crops were less than 1.5 m tall) a drop-disc was used to measure height above ground-level. Where the crop exceeded 1.5 m height, distance from the ground to the topmost ligule on five individual stems was measured and the mean recorded. At the same five points, a light meter (British Gas Energy Studies

Measuring Instrument Mk2, Portec, Milton Keynes) was used to take an ambient lux reading at ground level within the crop. A reading was also taken above (*Phalaris*) or outside the crop (*Miscanthus*) in order to calculate percentage shading by the crop (i.e. % reduction in ambient light flux between the top and bottom of the crop height).

Surveys of non-crop vegetation were performed in the survey periods April, August and December 2008 at all field sites (excepting the December survey at site 'HM', due to the destruction of the crop for rhizome extraction). A 50 cm × 50 cm quadrat was placed at five positions 2 m apart in each transect within the crops and headlands. Ground cover of each plant species, litter, bryophytes and bare ground was estimated visually and recorded as a percentage. Percentage cover of vegetation was not estimated in the comparison plots: the grasses in the grazed pastures were kept very short by livestock and therefore lacked many of the necessary identifying features (i.e. ligules and infloresences), and the blackcurrant fields had very little non-crop vegetation due to regular harrowing between rows of crop plants and herbicide application.

2.2.5 Data analysis

Tests for normality of distribution of the vegetation data showed a non-Gaussian distribution. Non-parametric Kruskal-Wallis tests were therefore used to test for differences in percentage ground cover and weed species number between habitats and at different distances within the crops. Effects of shading by the two crops were also tested for differences in this way. Diversity indices (Shannon-Wiener H and Simpson's E) were calculated for the vegetation in each habitat.

2.3 Results

2.3.1 Invertebrates

Over 12,500 individuals from 140 families/morphotypes in 18 orders were caught in the sweep nets, pan traps and pitfall traps across the habitats surveyed (Tables 2.2 – 2.5 for the 20 most abundant families in each habitat). In addition to this, individuals from the sub-order Lumbricina, class Gastropoda and order Lepidoptera formed part of the catch but were not identified to any higher taxonomic level, nor included in any analysis.

Table 2.2 The twenty most abundant invertebrate families/morphotypes in the comparison sites.

Order	Family / morphotype	Size range (mm)	Mean abundance	SE	Percentage
Diptera	Anthomyiidae	1-15	16.1	11.8	12.7
Collembola	Arthropleona	<1-15	11.0	3.4	8.6
Diptera	Bibionidae	1-15	9.1	8.4	7.2
Diptera	Chironomidae	<1-15	8.9	2.8	7.0
Diptera	Muscidae	1->15	7.7	4.4	6.1
Diptera	Sciaridae	1-15	7.1	2.2	5.6
Diptera	Scathophagidae	1-15	5.1	3.1	4.1
Diptera	Calliphoridae	5-15	4.3	3.0	3.4
Diptera	Phoridae	<1-15	4.2	2.6	3.3
Araneae	Linyphiidae	<1-5	3.9	0.9	3.1
Diptera	Ceratopogonidae	1-15	3.8	1.2	3.0
Diptera	Sphaeroceridae	1-5	2.9	0.9	2.3
Diptera	Sarcophagidae	5->15	2.2	1.6	1.7
Coleoptera	Staphylinidae	1->15	2.1	0.7	1.6
Hymenoptera	Braconidae	1-15	2.0	0.9	1.6
Hemiptera	Auchenorrhyncha	<1-15	1.9	0.8	1.5
Coleoptera	Unknown Larva	1-5	1.8	0.9	1.4
Diptera	Lonchopteridae	1-5	1.6	0.6	1.3
Hemiptera	Aphididae	<1-5	1.6	1.0	1.2
Diptera	Diastatidae	1-5	1.5	0.5	1.2

In terms of mean abundance per transect, *Phalaris* contained the highest number of invertebrate individuals (140), followed by the headlands (130), comparison sites (126) and then *Miscanthus* (66). A significant difference in the abundance of invertebrates was seen between the habitats (Kruskal-Wallis H (3, N = 81) = 8.772, $P = 0.032$. On pairwise comparisons (adjusted for multiple comparisons),

Table 2.3 The twenty most abundant invertebrate families/morphotypes in the headlands.

Order	Family / morphotype	Size range (mm)	Mean abundance	SE	Percentage
Diptera	Chironomidae	<1-15	16.4	6.8	12.7
Collembola	Arthropleona	<1-15	15.1	5.9	11.7
Diptera	Sciaridae	1-15	9.1	2.6	7.1
Diptera	Phoridae	<1-15	7.3	1.7	5.6
Diptera	Ceratopogonidae	1-15	5.5	1.8	4.3
Diptera	Anthomyiidae	1-15	5.5	1.3	4.2
Diptera	Scathophagidae	1-15	3.5	1.2	2.7
Thysanoptera	Phlaeothripidae	<1-5	3.4	2.8	2.6
Hymenoptera	Eulophidae	<1-5	3.0	1.1	2.4
Hymenoptera	Braconidae	1-15	2.9	1.1	2.3
Coleoptera	Carabidae	1- >15	2.9	1.5	2.3
Hymenoptera	Ichneumonidae	1-15	2.7	1.1	2.1
Diptera	Calliphoridae	5-15	2.5	1.2	1.9
Hemiptera	Auchenorrhyncha	<1-15	2.4	0.8	1.9
Araneae	Linyphiidae	<1-5	2.4	1.2	1.9
Hemiptera	Aphididae	<1-5	2.1	0.8	1.6
Coleoptera	Unknown Larva	1-5	2.1	1.4	1.6
Diptera	Sepsidae	1-15	1.8	0.8	1.4
Hemiptera	Pentatomoidea	1-15	1.6	0.7	1.2
Hymenoptera	Ceraphronidae	<1-5	1.6	0.7	1.2

Miscanthus was seen to have a significantly lower abundance of invertebrates than the headlands ($P = 0.019$).

Table 2.4 The twenty most abundant invertebrate families/morphotypes in the *Miscanthus*.

Order	Family / morphotype	Size range (mm)	Mean abundance	SE	Percentage
Collembola	Arthropleona	<1-15	9.3	2.7	13.7
Diptera	Chironomidae	<1-15	6.5	1.3	9.6
Diptera	Sciaridae	1-15	5.4	1.2	7.9
Diptera	Ceratopogonidae	1-15	3.0	0.7	4.3
Diptera	Phoridae	<1-15	2.9	0.8	4.3
Hymenoptera	Braconidae	1-15	2.3	1.0	3.3
Diptera	Anthomyiidae	1-15	2.2	0.6	3.2
Diptera	Sphaeroceridae	1-5	2.0	1.2	2.9
Hymenoptera	Eulophidae	<1-5	1.9	0.6	2.8
Diptera	Scathophagidae	1-15	1.9	0.5	2.8
Hymenoptera	Ichneumonidae	1-15	1.7	0.6	2.6
Diptera	Diastatidae	1-5	1.5	0.7	2.2
Hymenoptera	Scelionidae	1-5	1.5	0.8	2.2
Hymenoptera	Ceraphronidae	<1-5	1.3	0.5	1.9
Hymenoptera	Figitidae	<1-5	1.2	0.5	1.7
Diptera	Muscidae	1->15	1.1	0.4	1.6
Hemiptera	Aphididae	<1-5	1.1	0.3	1.6
Coleoptera	Carabidae	1- >15	1.1	0.3	1.6
Coleoptera	Staphylinidae	1->15	1.0	0.3	1.5
Araneae	Linyphiidae	<1-5	1.0	0.3	1.4

Table 2.5 The twenty most abundant invertebrate families/morphotypes in the *Phalaris*.

Order	Family/morphotype	Size range (mm)	Mean abundance	SE	Percentage
Diptera	Sciaridae	1-15	19.4	10.7	13.9
Diptera	Calliphoridae	5-15	15.7	9.9	11.3
Diptera	Anthomyiidae	1-15	8.8	3.8	6.3
Diptera	Chironomidae	<1-15	8.2	1.9	5.9
Diptera	Scathophagidae	1-15	7.1	2.2	5.1
Diptera	Muscidae	1->15	5.8	3.8	4.2
Collembola	Arthropleona	<1-15	5.4	1.8	3.9
Hemiptera	Aphididae	<1-5	5.3	4.1	3.8
Diptera	Sarcophagidae	5->15	4.9	2.7	3.5
Diptera	Ceratopogonidae	1-15	4.9	1.6	3.5
Coleoptera	Carabidae	1- >15	4.7	1.3	3.3
Hymenoptera	Ichneumonidae	1-15	3.3	1.2	2.4
Diptera	Diastatidae	1-5	3.1	0.9	2.2
Diptera	Phoridae	<1-15	3.1	0.8	2.2
Diptera	Bibionidae	1-15	2.5	1.5	1.8
Hymenoptera	Braconidae	1-15	2.3	0.6	1.7
Diptera	Sepsidae	1-15	2.0	0.8	1.5
Heteroptera	Pentatomoidea	<1-15	2.0	0.8	1.4
Hemiptera	Auchenorrhyncha	<1-15	1.9	0.4	1.3
Hymenoptera	Ceraphronidae	<1-5	1.8	0.7	1.3

The Diptera were the dominant invertebrate order in all habitats surveyed, comprising from 53% of the catch in both the headlands and *Miscanthus*, 67% in the comparison sites and 69% in *Phalaris* (Table 2.6). There was no significant difference between habitats in the prevalence of Diptera (Kruskal-Wallis H (3, N = 81) = 5.350 P = 0.148).

Table 2.6 Percentages of invertebrate orders comprising ≥5% of the catch in the different habitats. Orders comprising <5% of total catch are grouped together as 'Others'.

	Comparison	Headlands	*Miscanthus*	*Phalaris*
Diptera	67	53	53	69
Hymenoptera	7	12	17	10
Collembola	10	13	15	-
Hemiptera	-	5	-	7
Coleoptera	5	7	6	7
Others	11	10	9	8

2.3.2 Habitat differences

The most abundant orders were tested for differences between crops/habitats using a Kruskal-Wallis test. No significant differences were seen for Diptera, Collembola, Coleoptera, Hemiptera or Hymenoptera, but the abundance of Araneae was significantly different between habitats (Kruskal-Wallis H (3, N = 81) = 14.117,

P = 0.003). Pairwise comparisons (adjusted for multiple comparisons) showed significantly lower abundances in the *Miscanthus* and *Phalaris* than the comparison sites (P = 0.002 and P = 0.01 respectively, Table 2.7).

Table 2.7 Mean number of spiders (Araneae) caught per transect in the different habitats.

	Comparison sites	Headlands	*Miscanthus*	*Phalaris*
Araneae	6.1 ±1.3	4.5 ±1.9	2.1 ±0.5	2.3 ±0.4

The Diptera were further analyzed by comparing the abundance of the different infraorders across habitats using a Chi-squared median test. No significant differences were seen in the abundance of any infraorder between habitats surveyed (Table 2.8).

Table 2.8 Results from a Chi-square median test for differences in abundance of dipteran infraorders in the different habitats. Df = 3.

Dipteran infraorder	Chi-square	P- value
Asilomorpha	2.208	0.531
Muscomorpha	6.849	0.077
Bibionomorpha	0.489	0.921
Culicomorpha	3.406	0.333
Psychodomorpha	3.363	0.339
Tipulomorpha	0.671	0.880

There were, however, significantly more Muscomorpha families in the headlands (mean 10.1) compared with the *Miscanthus* (mean 5.2, Kruskal-Wallis H (3, N = 81) = 13.041, P = 0.005).

A similar analysis was made of the hymenopteran suborders and their constituent groups: Apocrita (Aculeata and Parasitica) and Symphyta. The abundance of individuals from the Parasitica and Symphyta were not significantly different between habitats (Kruskal-Wallis H (3, N = 81) = 1.271, P = 0.736 and H = 5.973,

P = 0.113 respectively). However, Aculeata abundance was significantly different between habitats (Kruskal-Wallis H (3, N = 81) = 15.027, P = 0.002) but multiple comparisons did not identify any significant pairwise differences due to high variability in the comparison sites. When the data from the comparison sites were omitted from the analysis, a significantly higher mean number of individuals from the Aculeata were present in the headlands (mean 0.8 ±0.46) compared with the *Miscanthus* (mean 0.04 ±0.04), which on multiple comparisons was a significant difference (Kruskal-Wallis H (2, N = 70) = 12.895, P = 0.025). The mean number of Aculeata families was also significantly different between the four habitats (Kruskal-Wallis H (3, N = 81) = 16.756, P < 0.001). A higher abundance of families was seen in the headlands (0.9 ±0.3) than the *Miscanthus* (0.07 ±0.05) which was shown to be a significant difference on pairwise comparison (P = 0.033).

2.3.3 Invertebrate families

The highest number of invertebrate families (excluding the taxa which were identified to morphotype or order only) were found in the headlands, followed by *Phalaris*, *Miscanthus* and the comparison sites (Table 2.9), although these were not significant differences (Kruskal-Wallis H (3, N = 41) = 1.344, P = 0.72).

Table 2.9 Abundance of invertebrate families in the different habitats surveyed.

Habitat	Total families	Mean per visit/site	SE	Range
Comparison	88	27.7	5.63	09-53
Headlands	108	29.7	4.65	11-59
Miscanthus	92	22.0	3.65	07-42
Phalaris	100	28.6	6.48	06-56

Within the different orders, the Diptera contained the highest number of families (51) recorded across the different habitats. The highest number of Dipteran families recorded in any one habitat was 43 in *Phalaris*. However, no significant differences existed between habitats for any invertebrate family in the Araneae, Coleoptera, Diptera, Hymenoptera, Opiliones or Thysanoptera (Table 2.10).

Table 2.10 A summary of the numbers of individual families identified for each invertebrate order in the different habitats.

	Comparison	Headlands	*Miscanthus*	*Phalaris*
Acari	4	5	4	4
Araneae	7	6	8	6
Coleoptera	15	14	12	15
Dermaptera	-	1	-	-
Diplopoda	1	3	2	2
Diptera	35	42	38	43
Hemiptera	5	8	5	6
Hymenoptera	16	22	18	19
Isopoda	2	3	2	1
Lithobiomorpha	-	1	1	1
Thysanoptera	2	1	-	1
Trichoptera	1	2	2	2

The only group to show a significantly different distribution was the morphotype "Auchenorrhyncha" (Hemiptera, Kruskal-Wallis H (3, N= 81) =15.475, $P = 0.002$) which was significantly more abundant in the *Phalaris* than the *Miscanthus* (mean per visit 6.2 ±2.21 and 0.64 ±0.24 respectively, Table 2.11).

Table 2.11 P – values from pairwise comparisons (adjusted for multiple comparisons as part of an overall Kruskal-Wallis test) for the abundance of the morphotype "Auchenorrhyncha" in the different crop habitats.

	Comparison	Headlands	*Miscanthus*
Headlands	>0.999		
Miscanthus	0.109	0.031	
Phalaris	>0.999	>0.999	0.006

Some invertebrate families were recorded in every habitat, whilst others only appeared in a single habitat (Table 2.12).

Table 2.12 Invertebrate families recorded in either all habitats, or only one. Figures in parentheses denote the total number of individuals recorded. C = comparison sites, H = headlands, M = *Miscanthus*, P = *Phalaris*.

Families recorded in all habitats		Families recorded in only one habitat		
Order	**Family**	**Order**	**Family**	**Habitat**
Acari	Tetranychidae (49)	Araneae	Aegelinidae (6)	C
Araneae	Araneidae (20)		Lycosidae (3)	C
	Linyphiidae (64)		Metidae (1)	H
	Thomisidae (7)	Coleoptera	Anthribidae(1)	H
Coleoptera	Lathridiidae (16)		Apionidae(1)	P
	Ptilidae (58)		Byrrhidae (1)	C
	Scarabaeidae (4)		Cerambycidae (1)	C
	Staphylinidae (70)		Chrysomelidae (2)	P
Diptera	Anisopodidae (17)		Histeridae (1)	C
	Anthomyiidae (982)		Hydraenidae (1)	H
	Asteiidae (112)		Nitulididae (2)	H
	Bibionidae (434)		Oedemeridae (1)	P
	Calliphoridae (885)	Dermaptera	Forficulidae (2)	H
	Camillidae (12)	Diptera	Aulacigastridae (2)	H
	Cecidiomyiidae (90)		Chamaemyiidae (1)	M
	Ceratopogonidae (447)		Clusiidae (13)	M
	Chironomidae (994)		Lauxanidae (5)	H
	Chloropidae (46)		Odiniidae (1)	H
	Culicidae (6)		Periscelididae (1)	P
	Diastatidae (208)		Pipunculidae (1)	H
	Dolichopodidae (39)		Platystomatidae (1)	H
	Drosophilidae (37)		Psilidae (1)	P
	Empididae (55)		Ptychopteridae (1)	P
	Fanniidae (44)		Rhinophoridae (1)	H
	Lonchopteridae (131)		Simuliidae (1)	H
	Muscidae (321)		Stratiomyidae (1)	P
	Mycetophilidae (56)		Thaumaleidae (1)	M
	Opomyzidae (18)	Hemiptera	Miridae (2)	H
	Phoridae (425)	Hymenoptera	Andrenidae (3)	H
	Scathophagidae (562)		Cynipidae (17)	M
	Scatopsidae (24)		Eumenidae (1)	H
	Sciaridae (1115)		Formicidae (6)	C
	Sepsidae (153)		Halictidae (1)	H
	Sphaeroceridae (174)		Trichogrammatidae (32)	M
	Syrphidae (64)			
	Tipulidae (12)			
Hemiptera	Aphididae (260)			
	Pentatomidae (118)			
Hymenoptera	Braconidae (249)			
	Ceraphronidae (102)			
	Diapriidae (22)			
	Eulophidae (204)			
	Figitidae (81)			
	Ichneumonidae (233)			
	Mymaridae (54)			

Families recorded in all habitats	
Order	**Family**
Hymentoptera	Proctotrupidae (35)
(cont.)	Pteromalidae (17)
	Scelionidae (55)
	Tenthredinidae (50)
Thysanoptera	Aelothripidae (107)
	Thripidae (55)

2.3.4 Size classes

In the pan trap and sweep net samples, the size class containing the highest numbers of invertebrates was 1-5 mm, and this was true of all habitats surveyed. *Phalaris* contained higher numbers of invertebrates in the size class 5-15 mm and *Miscanthus* the lowest, but these were not statistically significant differences (Kruskal-Wallis H (3, N = 91) = 5.140, $P = 0.162$), Figure 2.1.

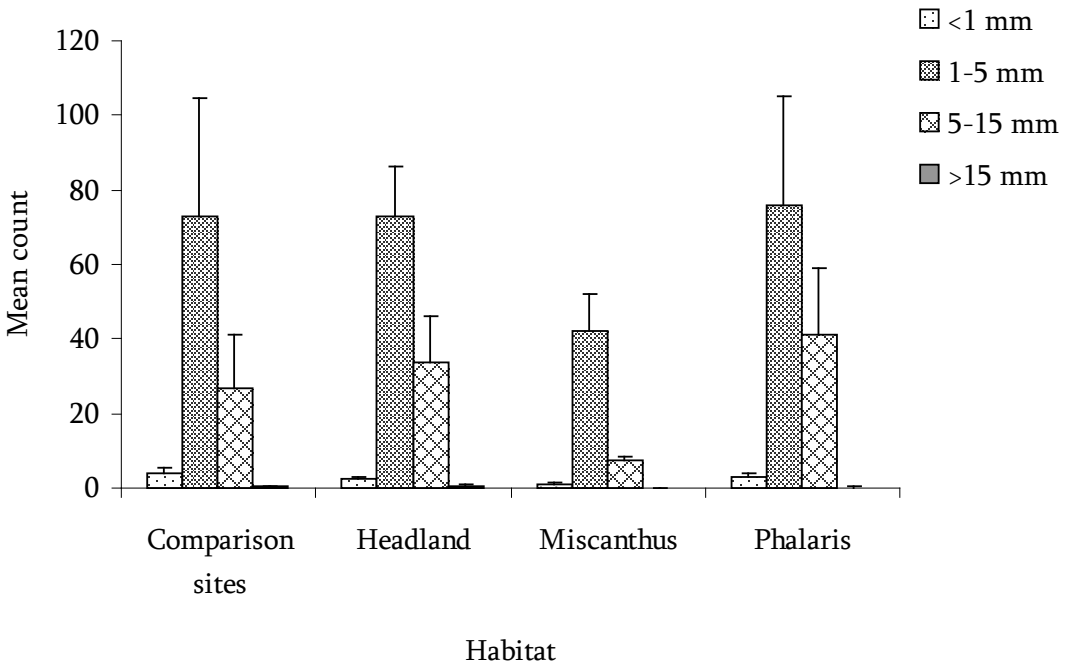

Figure 2.1 Mean counts ±1SE of the different size classes of invertebrates trapped in pan traps and by sweep netting.

2.3.5 Distance into the crop

No significant differences in the abundance of any invertebrate orders or size classes were found between crop transects at distances of 10 m, 20 m or 50 m from the crop edge (Table 2.13).

Table 2.13 Results from a Kruskal-Wallis test for differences in the abundance of the most common orders of invertebrates in the different transects in the crops *Miscanthus* and *Phalaris*. N = 27, df = 2.

Order	Kruskal Wallis H	*P* - value
Acari	1.940	0.379
Araneae	1.095	0.578
Coleoptera	1.024	0.599
Collembola	1.481	0.447
Diplopoda	0.356	0.837
Diptera	0.873	0.646
Hemiptera	0.333	0.847
Hymenoptera	0.688	0.709
Isopoda	0.238	0.888
Opiliones	1.661	0.436
Thysanoptera	0.408	0.815

2.3.6 Seasonal changes

Significant differences existed in the abundance of invertebrates in all habitats between the different months in which sampling took place (Kruskal-Wallis H (2, N = 81) = 46.931, $P < 0.0001$, Figure 2.2). GLM showed that across all habitats, invertebrate abundance was significantly higher in August than in April or in December (estimate for April = -7.363 ±1.058, z-value = -6.958, $P < 0.0001$ and for December estimate = -9.093 ±1.023, z-value = -8.717, $P < 0.0001$).

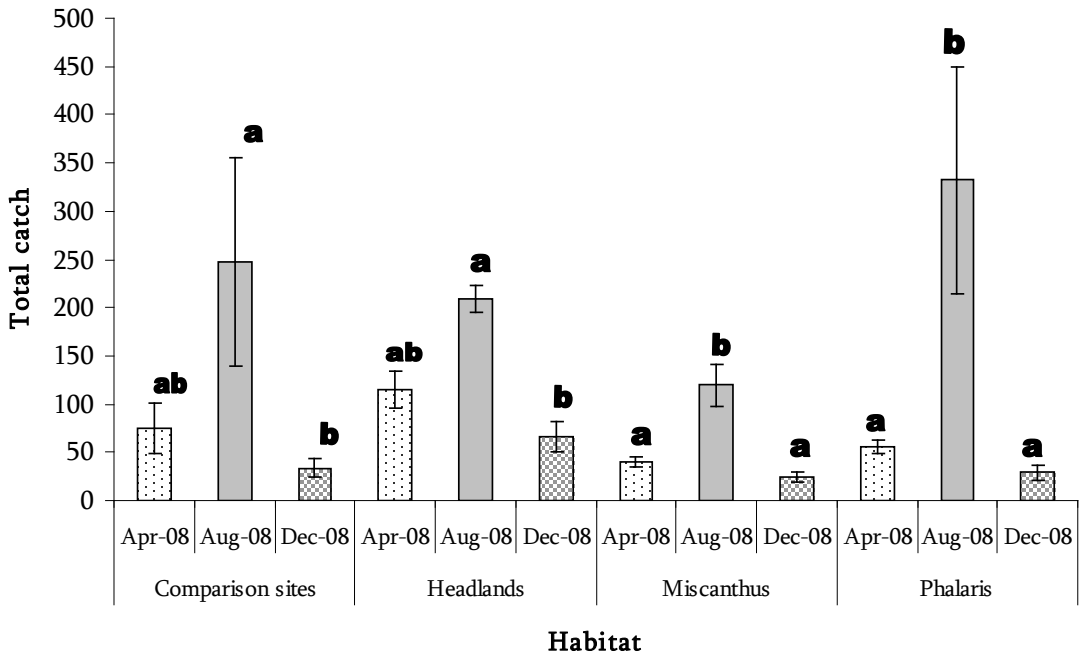

Figure 2.2 Comparisons between months of sampling for invertebrate abundance in the different habitats. In each habitat, 'a' = significantly different from 'b', 'ab' = not significantly different from 'a' or 'b' (pairwise comparisons adjusted for multiple comparisons as part of an overall Kruskal-Wallis test, $P<0.05$) between months of sampling.

2.3.7 Sticky traps and height in *Miscanthus*

A total of 1,950 individuals from 11 orders were recorded on 30 sticky traps. Invertebrates from two orders were recorded in significantly different abundances at different heights: Hymenoptera (Kruskal-Wallis H (2, N = 30) = 12.994, P = 0.002) and Hemiptera (Kruskal-Wallis H (2, N= 30) = 8.163, P = 0.017). Significantly higher numbers of individuals of the two orders were found on the sticky traps nearest the ground compared with ones set in the canopy in *Miscanthus.* Pairwise comparisons (adjusted for multiple comparisons as part of an overall Kruskal-Wallis test) showed these to be significant differences (P < 0.001 for Hymenoptera and P = 0.023 for Hemiptera, Figure 2.3). There was also a significant difference in terms of the richness of Hymenoptera families present at the three heights of sticky trap Kruskal-Wallis H (2, N= 30) = 7.358, P = 0.025. Family richness was significantly higher in the lower traps (mean 7.7 families) compared with the canopy traps (mean 4.8 families, pairwise comparison P = 0.02).

When examined in more detail, two individual Hymenopteran families showed significant differences between the bottom and top traps: Mymaridae (Median test, Chi-Square = 7.200, df = 2, P = 0.027) and Figitidae (Median test: Chi-Square = 11.429, df = 2, P = 0.003). Platygastridae were the only family with the highest abundance in the middle-height traps, and this was a significant result (Median test: Chi-Square = 7.500, df = 2, P = 0.024).

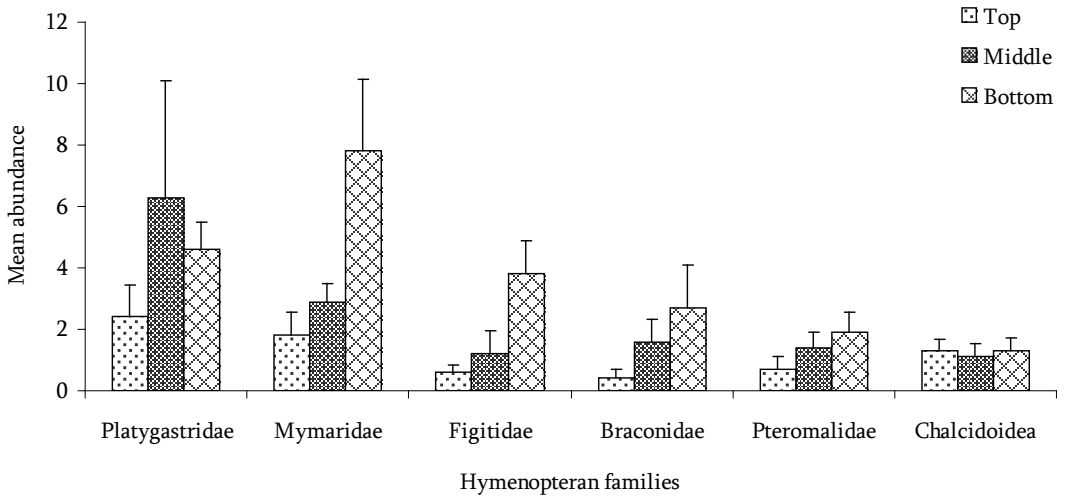

Figure 2.3 Abundance of the different Hymenopteran families at different heights within *Miscanthus* crops in August 2008 as sampled by sticky traps. Figures are means ±1SE.

2.3.8 Diversity indices

Simpson's 'E' and Shannon-Wiener 'H' diversity indices were calculated using the number of families present in each crop/habitat. *Miscanthus* scored the highest Simpson's Index score and the headlands had the highest Shannon-Wiener score and family richness (Table 2.14).

Table 2.14 Measures of invertebrate diversity in the different habitats surveyed.

	Invertebrate family richness	Shannon-Wiener H	Simpson's E
Comparison sites	98	3.50	0.76
Headlands	118	3.64	0.76
Miscanthus	101	3.57	0.77
Phalaris	115	3.45	0.73

2.3.9 Lepidoptera

Eleven butterfly species were recorded in the crops, headlands and comparison sites. *Phalaris* and the headlands contained the highest number of species (9 and 7 respectively, Table 2.15).

Table 2.15 Butterfly species recorded in the different habitats. * indicates a sighting in that habitat.

Butterfly species	Comparison sites	Headlands	*Miscanthus*	*Phalaris*
Lycaenidae				
Small copper *Lycaena phlaeas*				*
Nymphalidae				
Comma *Polygonia c-album*		*		
Painted lady *Vanessa cardui*		*		*
Red admiral *Vanessa atalanta*	*	*	*	
Small tortoiseshell *Aglais urticae*	*		*	*
Pieridae				
Green veined white *Pieris napi*				*
Large white *Pieris brassicae*	*		*	*
Small white *Pieris rapae*	*	*		*
Satyridae				
Meadow brown *Maniola jurtina*		*		*
Ringlet *Aphantopus hyperantus*		*		*
Speckled wood *Pararge aegeria*		*	*	*
Total species	**4**	**7**	**4**	**9**

Most of the butterfly activity (excluding the Pieridae) was centred on flowers of the Asteraceae such as knapweed *Centaurea nigra*, ragwort *Senecio jacobea*, ox-eye daisy *Leucanthemum vulgare* and thistles *Cirsium* spp. Caterpillars of the elephant hawkmoth *Deilephila elpenor* (Sphingidae) were seen on willowherbs (Onagraceae) within the *Phalaris* crops at multiple sites.

2.3.10 Vegetation

At the time that maximum crop height was reached in the December 2008 surveys, mean percentage cover of both the crops and weeds was significantly higher in *Phalaris* than *Miscanthus* (Table 2.16). All other forms of ground cover were higher in *Miscanthus*, although this difference was statistically significant only for litter and bare ground.

Table 2.16 Mean percentage ground cover in both crops and significant differences as defined by Mann-Whitney U- test.

	Miscanthus		*Phalaris*			
Ground cover type	Median	Inter-quartile range	Median	Inter-quartile range	*Z* - value	*P*- value
Crop cover	20.0	52.9	37.9	47.3	-3.924	<0.0001
Weeds	9.1	19.6	25.9	28.4	-5.474	<0.0001
Crop litter	27.9	42.7	0	0	9.504	<0.0001
Other litter	0	0	0	0	0.410	0.682
Bare ground	0	6.9	0	0	2.371	0.018
Bryophytes	0	0	0	0	0.193	0.847

Areas of *Miscanthus* crops included in the quadrats surveyed, contained 29 identified weed species, with the most abundant being broadleaved willowherb *Epilobium montanum* (mean 4.9% ±1.02% ground cover), creeping buttercup *Ranunculus repens* (4.3% ±0.72%) and broad leaved dock *Rumex obtusifolius* (3.4% ±0.86%). *Phalaris* contained 37 weed species, with creeping buttercup (7.6% ±1.24%), broad leaved dock (6.5% ±1.03%) and annual meadow grass *Poa annua* (5.2% ±0.78%) dominating. Headlands contained 50 plant species, dominated by Yorkshire fog *Holcus lanatus* (21.7% ±2.79%), creeping buttercup (15.2% ±1.94%), and cocksfoot *Dactylis glomerata* (7.2% ±1.77%). Table 2.17 & 2.18 list the non-crop vegetation species recorded and the habitats in which they were found.

Table 2.17 Dicotyledonous weed species found in the different habitats. Asterisk indicates presence in that habitat. H = headlands, M = *Miscanthus* & P = *Phalaris*.

Order	Family	Plant name	H	M	P
Apiales	Apiaceae (Umbellifer)	Hogweed *Heracleum sphondylium*	*		
		Upright hedge parsley *Torilis japonica*	*		
	Araliaceae (Ivy)	Ivy *Hedera helix*	*		
Asterales	Asteraceae(Daisy)	Lesser burdock *Arctium minus*	*		
		Black knapweed *Centaurea nigra*			*
		Creeping thistle *Cirsium arvense*	*	*	*
		Meadow thistle *Cirsium dissectum*	*	*	*
		Spear thistle *Cirsium vulgare*		*	*
		Prickly lettuce *Lactuca serriola*		*	
		Oxeye daisy *Leucanthemum vulgare*	*		*
		Ragwort *Senecio jacobaea*	*		
		Sow thistle *Sonchus oleraceus*			*
		Dandelion *Taraxacum* spp.	*	*	*
Boraginales	Boraginaceae (Borage)	Forgetmenot *Myosotis* spp.			*
Brassicales	Brassicaceae (Crucifer)	Hairy bittercress *Cardamine hirsuta*	*		*
Caryophyllales	Amaranthaceae (Amaranth)	Common orache *Atriplex patula*		*	
	Caryophyllaceae (Pink)	Mouse ear *Cerastium fontanum*	*	*	*
		Stitchwort *Stellaria media*	*		
	Polygonaceae (Knotweed)	Redshank *Persicaria maculosa*			*
		Knotgrass *Polygonum aviculare*		*	
		Sorrel *Rumex acetosa*	*		*
		Curled dock *Rumex crispus*	*		
		Broadleaved dock *Rumex obtusifolius*	*	*	*
Ericales	Myrsinaceae (Myrsine)	Scarlet pimpernel *Anagallis arvensis*		*	
Fabales	Fabaceae (Legume)	Birdsfoot trefoil *Lotus corniculatus*	*	*	*
		Red clover *Trifolium pratense*	*		*
		White clover *Trifolium repens*	*	*	*
Gentianales	Rubiaceae (Bedstraw)	Goosegrass *Galium aparine*	*		
Geraniales	Geraniaceae (Geranium)	Cut-leaved cranesbill *Geranium dissectum*	*		*
		Dove's-foot cranesbill *Geranium molle*	*		*
		Herb Robert *Geranium robertianum*	*		
Lamiales	Lamiaceae (Mint)	Ground ivy *Glechoma hederacea*	*		
		Self heal *Prunella vulgaris*	*		*
		Hedge woundwort *Stachys sylvatica*	*		
	Oleaceae	Ash *Fraxinus excelsior*	*	*	
	Plantaginaceae (Plantain)	Ribwort plantain *Plantago lanceolata*	*		*
		Broadleaved plantain *Plantago major*	*		
		Field speedwell *Veronica persica*			*
		Thyme-leaved speedwell *Veronica serpyllifolia*	*	*	*
Myrtales	Onagraceae (Willowherb)	Rosebay willowherb *Chamaenerion angustifolium*	*	*	*
		Great willowherb *Epilobium hirsutum*		*	*
		Broadleaved willowherb *Epilobium montanum*	*	*	*
Pteridales	Dennstaedtiaceae (Fern)	Bracken *Pteridium aquilinum*	*		
Ranunculales	Ranunculaceae (Buttercup)	Creeping buttercup *Ranunculus repens*	*	*	*
Rosales	Rosaceae (Rose)	Wild strawberry *Fragaria vesca*	*		
		Blackthorn *Prunus spinosa*	*		*
		Dog rose *Rosa canina*		*	
		Bramble *Rubus fructicosus*	*		
		Raspberry *Rubus idaeus*	*		
	Urticaceae (Nettle)	Nettle *Urtica dioica*	*	*	*

Table 2.18 Monocotyledonous weed species found in the different habitats. Asterix indicates presence in that habitat. H = headlands, M = *Miscanthus* & P = *Phalaris*.

Order	Family	Plant name	H	M	P
Poales	Juncaceae (Rush)	Soft rush *Juncus effusus*	*	*	*
		Woodrush *Luzula campestris*	*		
	Poaceae (True grasses)	Bent grass *Agrostis* spp.	*	*	*
		Sweet vernal grass *Anthoxanthum odoratum*	*		
		False oatgrass *Arrhenatherum elatius*	*		
		Crested dogstail *Cynosurus cristatus*	*	*	
		Cocksfoot *Dactylis glomerata*	*		*
		Couch grass *Elymus repens*		*	*
		Yorkshire fog *Holcus lanatus*	*	*	*
		Perennial ryegrass *Lolium perenne*	*		*
		Annual meadowgrass *Poa annua*	*	*	*
		Smooth meadowgrass *Poa pratensis*	*	*	*
		Rough meadowgrass *Poa trivialis*	*	*	*

The mean weed species number per quadrat was highest in the headlands (Table 2.19) and in this respect, every habitat was significantly different from each other (Kruskal-Wallis H (2, 395) = 106.609, P <0.001).

Table 2.19 Comparisons of mean numbers of weed species per quadrat between the different habitats surveyed.

Habitat	Mean no. of weed species	SE	Range	N	*P*-value (corrected for multiple comparisons)		
					Headlands	*Miscanthus*	*Phalaris*
Headlands	3.92	0.159	1-9	118		<0.00001	0.00003
Miscanthus	1.62	0.109	0-7	140	<0.00001		<0.00001
Phalaris	2.86	0.158	0-7	137	0.00003	<0.00001	

2.3.11 Crop height

Maximum mean crop height was recorded in the December survey period. Mean crop height at this time was 2.73 m ± 0.06 m in *Miscanthus* (range 1.93 – 3.25 m), and 1.19 m ± 0.03 m in *Phalaris* (range 0.92 – 1.56 m). A maximum individual stem height of 1.81 m was recorded in *Phalaris* in October, but weathering of plant material and the bending over of some of the stems had caused some loss of height by the December survey.

Maximum canopy shading occurred in both crops in the October survey period, with a mean of just 5% ±0.7% of ambient light reaching ground level in *Miscanthus* and 7% ±0.9% in *Phalaris* (Figure 2.4). There were significant differences in the degree of shading between the two crops in April, August and October (Table 2.20 for Mann-Whitney U test results). After this time, the leaves started senescing and falling, resulting in increased ambient light reaching ground level.

Table 2.20 Results from Mann-Whitney U tests for differences in the percentage of ambient light reaching ground level between the two biomass crops at the different survey times.

Month of survey	*Miscanthus* Median	*Miscanthus* Inter-quartile range	*Phalaris* Median	*Phalaris* Inter-quartile range	U	Z	*P* - value
Apr-08	100.0	0	100	2.0	1072.5	2.225	0.026
Jun-08	14.5	24.9	19.4	26.0	1114.0	-0.934	0.350
Aug-08	3.4	5.9	22.1	34.8	615.0	-4.374	<0.0001
Oct-08	2.4	4.2	5.3	5.8	553.5	-2.867	0.004
Dec-08	13.2	9.7	10.7	40.7	600.0	0.141	0.888

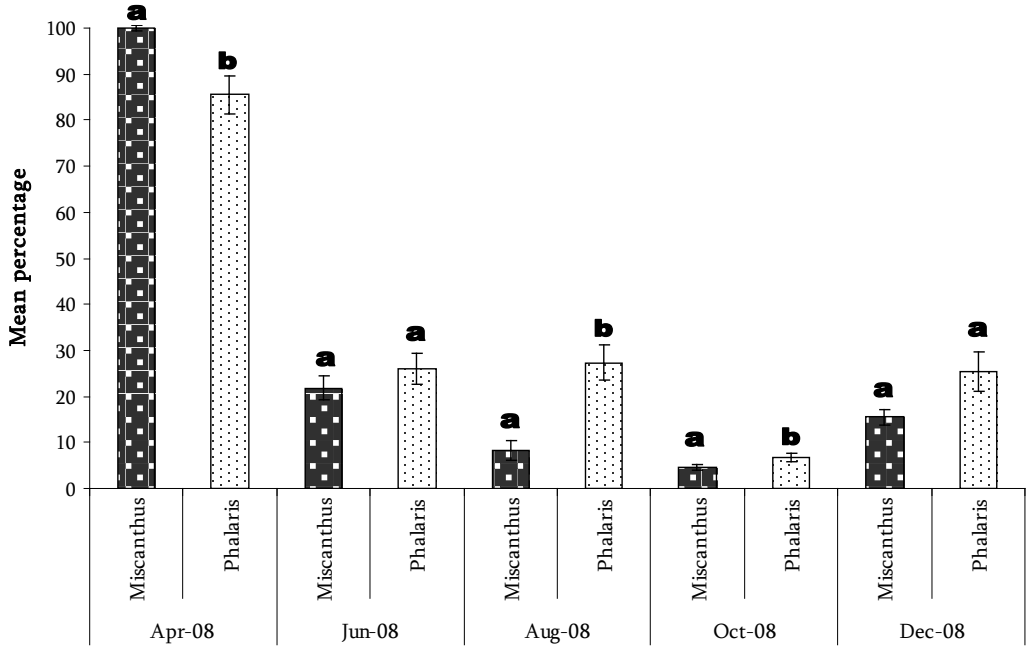

Figure 2.4 Percentage of ambient light reaching ground level in the two biomass crops at different times of year. Survey periods annotated with different letters indicate significant differences between the two crops (Mann-Whitney U test, $P<0.05$, as in Table 2.20).

2.3.12 Non-crop vegetation diversity

Vegetation species richness was highest in the headlands, but in terms of diversity indices (particularly the Simpson's Index), differences between the habitats were minimal (Table 2.21).

Table 2.21 Measures of diversity for the non-crop vegetation in the crops and headlands.

Habitat	Species richness	Simpson's E	Shannon H
Headlands	50	0.67	2.60
Miscanthus	29	0.68	2.32
Phalaris	37	0.67	2.40

2.3.13 Distance into crops

There were no significant differences in total weed abundance at the three different distances into either crop (Kruskal-Wallis H (2, N = 140) = 4.443, $P = 0.108$ and H (2, N = 137) = 1.325, $P = 0.516$ in *Miscanthus* and *Phalaris* respectively). Percentage cover of the crops was also not significantly different at different distances (Kruskal-Wallis H = (2, N = 140) = 0.466, $P = 0.792$ and H (2, N = 137) = 0.876, $P = 0.645$ in *Miscanthus* and *Phalaris* respectively).

2.4 Discussion

The sheer number of different plant species and invertebrate families identified in this study, together with the mammal and bird taxa described in other chapters makes analysis of this agro-ecosystem extremely complex. The relationships between trophic levels, biodiversity value and ecosystem services cannot be explored in their entirety, but the key ecological components of the different biomass crops can be identified.

2.4.1 Invertebrate composition

Generally, *Miscanthus* contained a lower abundance of invertebrates than the other habitats, but *Phalaris* and the headlands were more similar in terms of abundance and diversity of the assemblage.

In each habitat, the order Diptera was represented by a higher abundance of individuals than any other order. This is similar to the finding of Semere & Slater (2007), but differs from the results reported by Bellamy *et al.* (2009) who found that the order Hemiptera were most numerous, particularly on non-crop plants. Although their methodologies were similar (including sweep nets and pitfall traps amongst other techniques), differences in the methods of capture, time taken to sample the habitats and the distinction of results from weeds within the *Miscanthus* could explain any differences between these earlier studies and the present study. Nevertheless, this study showed the Collembolan 'Arthropleona' to be the most abundant invertebrate morphotype in *Miscanthus*, which was similar to results reported by Bellamy *et al.* (2009) from pitfall traps within a *Miscanthus* crop.

Although Semere & Slater (2007) did not report the relative proportions of different invertebrate orders, they did give a percentage abundance of families within each order. For example, in the Diptera, biomass cropped areas were dominated by the Bibionidae (March flies), Phoridae (scuttle flies) and Sciaridae (fungus gnats),

whereas in the field margins the three most abundant families were the Sciaridae, Anthomyzidae and Chloropidae (grass flies). The current study also recorded higher numbers of dipteran and hymenopteran families both in the crops and margins than Semere & Slater (2007), Table 2.22. Some of the variation between their work and this study could be explained by differences in survey techniques and timings. For example, Bibionidae adults are present in large numbers for only a few weeks in a year (Ball 2008), so may appear in disproportionately high numbers if the only surveys that are performed coincide with that time. Other possible factors to explain these differences between studies could be landscape-level differences in local habitat as well as a more mature crop and denser architecture. If the latter were the case, the reasons for a more diverse and abundant invertebrate assemblage in the older crop in this study than found by Semere & Slater (2007) could be related to longer term lack of soil disturbance (and therefore the opportunity for soil-dwelling invertebrates to complete their life-cycles), greater input of litter from fallen leaves and an increased three-dimensional area of more mature crop habitat in the present study.

Table 2.22 Comparisons of abundance of dipteran and hymenopteran families reported in this study and that of Semere & Slater (2007) (S&S).

	Miscanthus crop		*Phalaris* crop		Field margins	
	This study	S & S	This study	S & S	This study	S & S
Diptera	38	13	43	9	42	16
Hymenoptera	18	4	19	3	22	6

The most abundant invertebrate families in each habitat all have very different ecology and life histories. The Anthomyiidae (root maggot flies of the order Diptera) were the predominant family in the headlands. Their larvae are phytophagous (as leaf miners or root maggots), saprophagous or exist as parasitoids of other insects (Ball 2008). The adults can be found feeding on dung, carrion and decaying plant matter as well as flowers and they may have a role as pollinators. In the headlands, the non-biting midges (Diptera: Chironomidae) were the most abundant. Some of the larvae have a terrestrial existence, but many species are

aquatic or semi-aquatic, feeding on organic matter and plankton. The adults do not need to feed in their short existence, but will take nectar from flowers (Ball 2008). The dark-winged fungus gnats (Diptera: Sciaridae) have predominantly terrestrial larvae, which have an important role in soil and litter, feeding mainly on fungal mycelium. The adults only ingest liquids and die after reproducing, a few days after emerging (Ball 2008). Finally, in *Miscanthus*, the Collembolan morphotype 'Arthropleona' comprised the highest percentage of invertebrate individuals. Collembola play an important role in translocating carbon from surface litter into the soil (Chamberlain *et al*. 2006) and their increased presence in the *Miscanthus* may be linked to the large amount of crop litter on the soil surface.

Although it was not a significant difference, in this study, the highest number of individual invertebrates was recorded in *Phalaris* and the lowest in *Miscanthus*. Whether this was a real difference between crop species, or merely the result of structural differences influencing the effectiveness of trapping methods is not clear.

2.4.2 Invertebrates unique to crop habitat

Twelve families from the Coleoptera, Diptera and Hymenoptera were only recorded in biomass crop habitats and not in the comparison sites or headlands. In *Phalaris*, three coleopteran families were unique, but recorded in very low numbers: Apionidae (seed weevils), Chrysomelidae (leaf beetles), and Oedemeridae (pollen beetles or false-blister beetles). These families are all associated with herbaceous plants, feeding on plant material, pollen or nectar (www.bugguide.net).

The two hymenopteran families unique to *Miscanthus* are both parasitic. The Cynipidae are gall wasps generally associated with woody plant species such as oak (*Quercus* spp.) and either directly form galls, or act as inquilines, i.e. are unable to induce galls themselves, but inhabit, modify and feed from those formed by other species (Stone *et al*. 2002). Trichogrammatidae are egg parasitoids, utilising a wide

range of host eggs from several orders (Richards 1977). Whilst it is more obvious that the hosts of Trichogrammatidae should be widely available within the *Miscanthus* crop, it is less clear what resources that are distinct from those available in *Phalaris* or the headlands are used by the cynipids in *Miscanthus*. Although caught in small numbers, they were present in *Miscanthus* at three sites. There were oaks in all the hedges surrounding both crops, yet the cynipids were not found in any of the adjacent headlands or the *Phalaris*.

Most dipterans unique to *Miscanthus* were also present in very low numbers, with only one individual each from Chamaemyiidae and Thaumaleidae. Clusiidae, which are usually associated with damp, deciduous forests (Ball 2008) were found in slightly higher numbers. Singletons of the dipteran families Periscelididae, Psilidae, Ptychopteridae and Stratiomyidae were unique to *Phalaris* crops.

2.4.3 Beneficial invertebrates in the crops

It has been reported that individuals from 71 different Dipteran families are anthophiles, visiting around 550 species of flowers (Larson *et al*. 2001). They are thought to play an important role in pollination, although there is a paucity of detailed published data available. Some anthophiles may not directly pollinate all the flowers they visit, but the resources gained from each flower may sustain the individual, ensuring that they are capable of pollinating the plant species reliant upon them (Kevan 1999). Flower resources may also sustain non-pollinating natural enemies, which require floral-derived food in order to complete their life cycles (Isaacs *et al*. 2009; Kevan 1999). As such, the presence of flowering weed species both in the biomass crops themselves and the headlands provide vital resources. This may be of particular importance in *Miscanthus* crops and their margins, in which there is potential for wild flowers and tussocky grasses to become well established during the 20 year life of the crop – a factor which has

been reported to increase natural enemy abundance in comparison with recently established margins (Denys & Tscharntke 2002).

Dipteran parasitoids that were present in the crops and headlands included individuals from the families Anthomyiidae, Phoridae, Pipunculidae, Rhinophoridae and Sarcophagidae, which have a wide range of hosts. Also present were dipteran families with predatory life stages (either as larvae or adult) including: Chamaemyiidae, Dolichopodidae, Drosophilidae (larvae), Empididae and Muscidae. Adults of the family Scathophagidae (dung flies) are significant predators on other flies and soft-bodied insects and therefore have a role as biological control agents. They have also been recorded as an important pollinator of the declining arable weed *Torilis arvensis* (spreading hedge parsley, Gibson *et al*. 2006) and their presence was recorded across all the habitats in this study.

The biomass crops were relatively low in abundance of spiders (of the family Araneae) in relation to the comparison plot fields. Most of the spider catch was in pitfall traps, and it is possible that the taller architecture and three-dimensional quality of the biomass crops compared with grazed pasture resulted in fewer interactions with the pitfall traps (and therefore opportunities to be caught by them). This was certainly suggested as a possibility by Meek *et al*. (2002), who seemed cautious about possible interpretation of pitfall trapping results due to this factor. Despite this, Linyphyiid spiders were caught in higher numbers than any of the other Araneae. They spin webs close to the ground and are a major predator of aphids, often capturing those that have fallen from taller vegetation (Schmidt & Tscharntke 2005).

Carabid beetles are effective predators of crop pests such as slugs, aphids, Diptera and some Lepidoptera as well as reducing weed seed biomass. They are negatively affected by deep tillage regimes and benefit from crop heterogeneity and weediness

(Kromp 1999). No representatives of the Coccinellidae were found in the biomass crops, but they were recorded in small numbers in the headlands, and a Harlequin ladybird *Harmonia axyridis* was trapped in August 2008 at the Herefordshire comparison site, which was soon after the species had first spread to that area (http://www.harlequin-survey.org). The Staphylinidae (rove beetles) are non-specific predators, preying on small arthropods such as Collembola, mites, insect larvae and nematodes. It has been proposed that staphylinid community structures could be used as an indicator of environmental quality and anthropogenic impact due to their ecological specialism (Bohac 1999).

Most of the Hymenoptera have important ecological roles as predators, parasitoids or pollinators. There were few Aculeata (predominantly pollinators) in the biomass crops themselves, but the headlands contained a more diverse assemblage of families. Larval Symphyta are an important food source for birds (Brickle *et al*. 2000) and both the headlands and *Phalaris* contained a similar number of these, although low numbers and high variability meant that there was no significant difference between the habitats surveyed.

When the Hymenoptera within *Miscanthus* crops were examined more closely through the use of yellow sticky traps, with the exception of two Symphyta adults, all other 555 hymenopteran individuals were from the sub-group Parasitica. This group has a range of hosts, which are parasitized at varying stages of development (summarised in Table 2.23). The presence of such parasitoids is thought to be indicative of good habitat quality, as they are dependent on resources from a very well established lower trophic level (Henson *et al*. 2009).

Two of the families (Mymaridae and Figitidae) were found in higher numbers close to ground level than high up in the *Miscanthus* canopy. This may be due partly to

Table 2.23 Life histories and hosts of the parasitic Hymenoptera trapped in *Miscanthus* crops. Information collated from Noyes (2003), Richards (1977) and www.bugguide.net.

Family	Hosts & life history (where described)
Braconidae	Hemiptera, Coleoptera adults, Lepidoptera larvae, Psocoptera nymphs, Diptera. Some are egg-larval parasitoids – eggs are laid in host eggs and only develop when the host reaches the larval stage. Many pupate in silk cocoons outside the host.
Ceraphronidae	Diptera, Thysanoptera, Lepidoptera and Neuroptera. Some hyperparasitize braconids in Hemiptera.
Cynipidae	Some parasitic, others gall makers or gall inquilines.
Diapriidae	Fungus gnats (Sciaridae) and other dipterans, Coleoptera.
Eulophidae	Hidden larvae e.g. leaf mining Lepidoptera & Hymenoptera, Thysanoptera, also a hyperparasitoid.
Figitidae	Diptera, Neuroptera and other Hymenoptera.
Ichneumonidae	Lepidoptera, Coleoptera larvae, Diptera larvae, other Hymenopterans.
Megaspilidae	Hemiptera, may also be hyperparasitoids.
Mymaridae	Insect eggs – often concealed e.g. in plant tissue or in soil. Not host specific – may parasitize several insect families. Most common hosts are eggs of Hemiptera, Coleoptera, Psocoptera, Odonata, Lepidoptera.
Platygastridae	Egg parasitoids – used as biological control for Lepidoptera and horse flies (*Tabanus*). Also parasitize Coccidoidea (Hemiptera) and Diptera.
Proctotrupidae	Araneidae and Hemiptera eggs, Coleoptera larvae, Sciaridae (Diptera), Myriapoda and Chilopoda.
Pteromalidae	Some hyperparasitoids, some adults may feed on body fluids of host after oviposition. Diptera, Coleoptera, Hymenoptera, Lepidoptera and Siphonaptera.
Torymidae	Coleoptera, Diptera.
Trichogrammatidae	Egg parasitoids: Lepidoptera, Hemiptera, Coleoptera, Thysanoptera, Hymenoptera, Diptera and Neuroptera.

host-seeking activities – Mymaridae are known to parasitize insect eggs concealed in the soil, but may also reflect the fact that weed flowers close to the ground are

providing essential nectar foraging resources (Kevan 1999). Trap height was also a significant factor for the abundance of Platygastridae sampled; as they were more abundant at the middle height. As parasitoids of Hemiptera and other eggs, it is likely that mid-height in the crop is the optimum place for both locating their host eggs and exploiting nectar resources.

2.4.4 Invertebrates as food resources

The highest numbers of invertebrates were recorded in the August sampling period, and the least in December. Amongst the pan trap and sweep net samples, the most abundant size of individuals was 1-5 mm, which are likely to be important in the diet of farmland passerine chicks (Morris *et al.* 2005). Although the bird nesting and fledgling-provisioning season is generally accepted to be from around March to September, most young birds have fledged by the beginning of August. Nevertheless, it is possible that the abundance of invertebrates seen in August is indicative of invertebrate abundance earlier during the breeding period. In order to confirm this, any further studies would need to sample chick food invertebrate resources within the crops more frequently to coincide with the breeding season.

Where invertebrate composition of the diet of farmland passerines has been reported from faecal samples, the importance of invertebrate families can vary between bird species, as demonstrated in the results of studies of four farmland passerines (Table 2.24).

Adult butterflies (Lepidoptera) were only surveyed through un-standardised encounters in this study, while adult moths and larval Lepidoptera (butterflies and moths) were not sampled directly at all.

Table 2.24 Percentages of important invertebrate groups in the diet of the chicks of whitethroat *Sylvia communis*, dunnock *Prunella modularis*, yellowhammer *Emberiza citrinella* (from Moreby & Stoate 2001) and reed bunting *Emberiza schoeniclus* (from Brickle & Peach 2004) as determined by faecal analysis.

	Whitethroat	Dunnock	Yellowhammer	Reed bunting
Araneae	14%	5%	9%	29%
Hemiptera	6%	3%	3%	
Lepidoptera larvae	29%	4%	18%	33%
Lepidoptera adults	10%	2%	11%	
Symphyta larvae	6%	1%	2%	
Curculionidae	9%	20%	8%	
Other Coleoptera	8%	33%	21%	15%
Diptera	12%	19%	24%	12%

Pitt (2009, unpublished) used Heath light traps set in *Miscanthus* and *Phalaris* to capture night-flying macro moths between April and August 2009. The study recorded 405 moths of 56 species and 18 different families and subfamilies, including nine species considered by IUCN to be 'vulnerable' (Table 2.25). Many of the moth species caught in both crops were species usually associated with deciduous trees, and it was thought that they may be roosting in the crops, rather than using them as breeding or feeding sites. Moth abundance was reported to be positively associated with crop height, and despite the light trap being very visible over a wide area immediately after harvest, this did not result in increased catch, as had been expected.

In the current study, a number of micro-moths (Momphidae) were caught on the sticky traps and further studies into these and other lepidopterans as food resources in biomass grass crops is required.

Table 2.25 Moth species classified as 'vulnerable' by the IUCN trapped by Pitt (2009 unpublished) in *Miscanthus* and *Phalaris*.

Moth species	Where recorded
August thorn *Ennomos quercinaria*	*Phalaris*
Buff arches *Habrosyne pyritoides*	*Miscanthus*
Buff ermine *Spilosoma luteum*	*Miscanthus*
Garden tiger *Arctia caja*	*Miscanthus*
Small phoenix *Ecliptopera silaceata*	*Miscanthus* & *Phalaris*
Small square-spot *Diarsia rubi*	*Miscanthus* & *Phalaris*
Shoulder-striped wainscot *Mythimna comma*	*Miscanthus*
Rustic *Hoplodrina blanda*	*Miscanthus* & *Phalaris*
White ermine *Spilosoma lubricipeda*	*Miscanthus* & *Phalaris*

Insectivorous small mammals such as the pygmy shrew take Opiliones, Araneae and adult Coleoptera as the most abundant prey items, while the common shrew also takes many earthworms (Pernetta 1976). Both of these shrew species rely on dense vegetative ground cover, and the biomass crops and headlands potentially provide excellent foraging habitat for them.

2.4.5 Weed abundance

The differing growth habits of the two crops appeared to highly influence the weed understorey. The greater crop cover and weed content (i.e. non-crop vegetation) in the *Phalaris* habitat compared with the *Miscanthus* habitat was attributable to a higher proportion of crop litter on the ground in between the *Miscanthus* clumps. Ambient light at ground level was at its lowest in both crops by October, when there was only a very small difference numerically (2%) in the degree of shading by the two crops, although this was a statistically significant difference. Although there were spaces between *Miscanthus* rhizome clumps, the canopy itself was more uniform than the *Phalaris* canopy, resulting in a 78% decrease in ambient light between measurements taken at ground level in April and June. Conversely, the

Phalaris stems were more evenly and densely packed together and the crop showed a slower increase in shading over time. Many of the weeds within the *Phalaris* in the later phases of crop growth were tall and had probably established early in the growing season, matching their growth with that of the crop. However, it seems less likely that any further weeds germinating under the dense *Phalaris* canopy would have had enough light to grow from seed once the *Phalaris* canopy closed. The smaller proportion of weeds in *Miscanthus* may have resulted from the effects of shading and the inability of any weeds to grow fast or tall enough to be able to compete for light and/or nutrients with the crop. Some other process may also have been responsible: the high levels of crop litter on the ground could inhibit germination and early growth of weeds, or allelopathy (i.e. phytochemicals produced by the *Miscanthus* resulting in inhibited growth of other plants) may be present. For example, leachate from both living and abscised foliage of *Miscanthus floridulus* in Taiwan was shown to contain phytotoxic compounds which inhibited the growth of lettuce *Lactuca sativa* (Chou & Chung 1974). No such effects have been reported for *M.* x *giganteus*, but it is possible that it is a trait common to other species in the *Miscanthus* genus and may therefore be in effect in the crop fields.

2.4.6 Invertebrate diversity and weed diversity

Different measures or indices of diversity within the areas surveyed gave different indications of the most diverse habitat. In terms of both invertebrate family and weed species richness, the headlands were the habitat with the highest biodiversity, followed by *Phalaris*. Shannon-Wiener's index was highest in the headlands for both weeds and invertebrates then *Miscanthus* for invertebrates and *Phalaris* for weeds. The highest Simpson's score was found in the *Miscanthus* for both groups, followed by the headlands and comparison sites / *Phalaris* for invertebrates. Measuring species number alone does not take evenness into account. Both the Simpsons and Shannon indices do account for evenness (rather than just species richness), but either communities containing low numbers of species and

individuals or those with an abundance of the more common species are biased in the calculations (Hill 1973). This factor has led to caution in utilising these measures of biodiversity in agroecosystems (Albrecht 2003). Despite this, they are still amongst the most commonly used measures of biodiversity and are well understood and easily calculated. For these reasons, they still have a role in quantifying the basic diversity of a system, even if they are not believed to be the ideal measures of biodiversity in every respect.

Increased plant diversity can support higher invertebrate abundance in agroecosystems regardless of the type of crop grown (Westbury *et al.* 2011). It could be tempting therefore, to attempt to quantify the relationships between plant and invertebrate diversity within the biomass crops and their headlands. This has not been done here for several reasons: (a) the data from the invertebrate trapping techniques used needs to be treated cautiously for reasons discussed below, (b) variability within and between the diversity indices used makes them unreliable for this purpose and (c) any relationships quantified in this way may result from local or landscape-level influences such as topography, climate or soil quality that may not translate to other geographical areas. Instead, known relationships between weeds and invertebrates are discussed below and from these, it is possible to infer how the weed community in the crops may influence invertebrate abundance and diversity.

2.4.7 Weed and invertebrate associations

A potential advantage of biomass grass crops is lack of disturbance, both through lack of tillage of the soil for the life of the crop, and because the senesced crops and their associated weed community are left standing throughout the winter, a factor which may enhance communities of arthropods. Collins *et al.* (2003) reported that the highest densities of overwintering polyphagous predators were associated with beetle banks sown with false oat grass *Arrhenatherum elatius* and cocksfoot

Dactylis glomerata compared with naturally regenerated areas, or those sown with crested dogstail *Cynosurus cristatus*. In this study, a small percentage of *D. glomerata* was found within *Phalaris* crops, but it comprised a larger percentage of the headlands, where it may play an important role as a winter refuge. As part of a biomass field structure, hedgerows may also hold benefit for invertebrates: Pywell *et al*. (2005) found a higher richness and abundance of both Araneae and Coleoptera in arable hedgerows in comparison with the field margins, and Schmidt *et al*. (2005) reported that landscape complexity and the presence of non crop habitats had more influence on epigeal spider species richness.

The value of weeds as a resource for higher trophic levels has been discussed earlier. Mauchline *et al*. (2005) even suggest that some of the resource-rich non-competitive weeds should be routinely tolerated in crops as a means of enhancing biodiversity and natural enemies. Information from the Database of Insects and their Food Plants was used to compile a list of all UK phytophagous invertebrates associated with the combination of non-crop plant species making up 90% of total ground cover in the two biomass crops and headlands (Table 2.26). The results of this show several hundred possible additional invertebrate species (subject to regional presence) from multiple families and orders that could be supported in an agricultural landscape where the two crops with their headlands and associated weeds are grown. These additional invertebrates are likely to contribute significantly as food resources for higher trophic levels.

Table 2.26 Potential value of the weeds within the different habitats to phytophagous invertebrates. Calculations are based on all invertebrate species associated with the weed species making up at least 90% ground cover in each habitat, data from the UK Database of Insects and their Food Plants (DIFP, formerly the Plant Insect Database), Biological Records Centre.

	Headlands		*Miscanthus*		*Phalaris*	
Order	Families	Species	Families	Species	Families	Species
Acari	1	4	1	4	1	5
Coleoptera	8	76	9	68	9	102
Diptera	10	95	9	86	9	84
Hemiptera	22	136	17	129	18	132
Hymenoptera	4	20	3	11	3	14
Lepidoptera	23	282	20	192	27	262
Orthoptera	1	1				
Thysanoptera	1	5	1	6	1	7
Total	70	619	60	496	68	606

The polyphagous invertebrates associated with plants have a diverse range of dietary habits. As an example, the range of herbivores associated with creeping buttercup, one of the three most abundant weeds in the crops and headlands, is given in Table 2.27.

Five nuisance weed species are listed under the Weeds Act (1959), namely spear thistle *Cirsium vulgare*, creeping or field thistle *Cirsium arvense*, curled dock *Rumex crispus*, broad-leaved dock *Rumex obtusifolius* and ragwort *Senecio jacobaea*. Although it is not illegal to have these weeds present on agricultural land, they must not be allowed to spread to neighbouring land or to any other areas used for grazing or making forage. Despite being nuisance plants in agricultural terms, these weeds also have important ecological functions. Bumblebees (*Bombus* spp.) and honeybees were recorded most frequently on *Cirsium* spp. in margins surrounding arable fields (Roy *et al*. 2003).

Ragwort is the main food plant of the cinnabar moth *Tyria jacobaeae* caterpillar and a further 94 phytophagous invertebrates are associated with it (DIFP). Broad-leaved dock also supports over 90 species of invertebrate, of which there are 39 macro-moths and 4 butterfly larvae (DIFP).

Table 2.27 Polyphagous and herbivorous invertebrates associated with creeping buttercup *Ranunculus repens*, as detailed in the Database of Insects and their Food Plants (DIFP).
Key: **Orders**: Aca = Acari, Col = Coleoptera, Dip = Diptera, Hem = Hemiptera Hym = Hymenoptera, Lep = Lepidoptera, Thys = Thysanoptera
Life stage: Ad = adult. La = larvae (where specified)
Mode of herbivory: B = boring, M = mining, G = galling, R = rolling (where specified)
Plant part attacked: L = leaves, F = flowers, S = stems, Rt = roots, (where specified).

			Life stage		Mode of herbivory				Plant part attacked			
Order	Family	Species	Ad	La	B	M	G	R	L	F	S	Rt
Aca	Eriophyidae	*Epitrimerus rhyncothrix*	*	*								
Col	Byturidae	*Byturus ochraceus*	*							*		
Col	Chrysomelidae	*Chrysolina staphylaea*	*	*					*			
Col	Chrysomelidae	*Hydrothassa glabra*	*	*								
Col	Chrysomelidae	*Hydrothassa marginella*	*	*					*			
Col	Chrysomelidae	*Plateumaris sericea*	*							*		
Col	Curculionidae	*Bagous tempestivus*		*							*	
Col	Curculionidae	*Barynotus moerens*	*						*			
Col	Curculionidae	*Leiosoma deflexum*		*							*	*
Col	Curculionidae	*Leiosoma oblongulum*										
Dip	Agromyzidae	*Napomyza nigritula*		*	*						*	
Dip	Agromyzidae	*Phytomyza fallaciosa*		*		*			*			
Dip	Agromyzidae	*Phytomyza notata*		*		*			*			
Dip	Agromyzidae	*Phytomyza ranunculi*		*		*			*			
Dip	Cecidomyiidae	*Dasineura ranunculi*		*			*	*	*			
Dip	Cecidomyiidae	*Dasineura traili*		*			*			*		
Dip	Syrphidae	*Cheilosia albitarsis*		*								*
Hem	Cicadellidae	*Eupteryx vittata*							*			
Hem	Aphididae	*Aulacorthum solani*							*	*		
Hem	Aphididae	*Dysaphis ranunculi*										
Hem	Aphididae	*Tubaphis ranunculina*							*			
Hem	Lachnidae	*Protrama ranunculi*										*
Hem	Pemphigidae	*Thecabius affinis*									*	
Hym	Tenthredinidae	*Monophadnus pallescens*		*					*			
Hym	Tenthredinidae	*Pseudodineura fuscula*		*		*			*			
Hym	Tenthredinidae	*Tenthredo mesomelas*		*								
Lep	Noctuidae	*Agrochola lychnidis*		*						*		
Lep	Noctuidae	*Trigonophora flammea*		*								
Lep	Noctuidae	*Noctua orbona*		*					*			
Lep	Tortricidae	*Cnephasia asseclana*		*		*			*	*		
Lep	Tortricidae	*Cnephasia genitalana*		*						*		
Lep	Tortricidae	*Cnephasia incertana*		*		*			*	*		
Lep	Tortricidae	*Cnephasia stephensiana*		*		*			*			
Thys	Thripidae	*Thrips discolor*		*					*			

The seeds of the weed, broadleaved dock are a favoured food of the bullfinch *Pyrrhula pyrrhula* (an amber-listed passerine) during the winter months (Newton 1999) and may also be of importance in the diet of small mammals. From an

ecological perspective, these weeds are therefore high-value habitat, even if they are undesirable in present-day agricultural management regimes.

2.4.8 Weeds as food resources for vertebrates

Many granivorous passerine birds associated with farmland are dependent on weed seeds, particularly during the winter. Marshall *et al*. (2003) list several weed species that are important to birds. Some of those found in the biomass crops include *Cerastium fontanum, Cirsium. arvense, Persicaria maculosa, Poa annua, Polygonum aviculare, Rumex obtusifolius* and *Sonchus oleraceus*. Holland *et al*. (2006) report a more general assemblage of plant families important to granivorous birds, which include in the order of importance: Poaceae, Polygonaceae, Caryophyllaceae, Cruciferae, Compositae, Chenopodiaceae and Labiatae. Most of these families (excepting Cruciferae and Chenopodiaceae) were present within the biomass crops and their headlands and are therefore likely to make these habitats a valuable resource for granivorous birds.

Weed flowers and seeds are important in the diet of the wood mouse on arable farmland, particularly from April to June before cereal endosperm becomes available (Green 1979). Indeed, within an otherwise homogenous cereal crop, the wood mouse will favour weed patches containing favoured seeds (Tew *et al*. 2000). The harvest mouse also takes a high proportion of weed seeds from winter to early spring, after which a greater proportion of green vegetation and invertebrates are taken (Trout 1978). Among the listed species of weed seed eaten by harvest mice, those present in the biomass crops include *Poa* spp., *Trifolium* spp., *Taraxacum* spp. and *Plantago* spp. Consumption of *Phalaris* seeds by harvest mice has been recorded in the wild (Trout 1978) and a commercial crop will therefore potentially provide a large seed resource for this species as well as other small mammals.

2.4.9 Limitations of survey methodology

The methodological factor which varies most between published invertebrate studies is the different trapping methodology. Whilst there is agreement about the need to use multiple techniques to cover as wide a range of taxa as possible (Moir *et al.* 2005; Standen 2000; Mommertz *et al.* 1996), the methods used and trapping regimes seem to be very dependent on expertise, manpower and available funding levels (Qi *et al.* 2008). In the present study, initial trials of pitfall traps set for seven days resulted in large catches of slugs (with a maximum of 147 in one trap). The quantities of slime produced were large, and it coated many of the other invertebrates in the catch. As a result, identification and counts were difficult and overly time-consuming due to the extra effort required to separate individuals in the sample from the slime sufficiently to show identifying features. The decision was therefore made to reduce the trap time to 24 hours, despite the fact that the subsequent catch may be reduced. Other authors report varied pitfall sampling times from 1 week (Smith *et al.* 2009; Thomas & Marsall 1999; Mommertz *et al.* 1996), 2-3 weeks (Mattoni & Longcore 2000) and up to 4 weeks (Meek *et al.* 2002). Duelli *et al.* (1999) proposed that a standard two week pitfall sampling period is appropriate. Although the 24 hour trapping period in this study is well below the recommended 2 weeks, it was replicated across the different sites, so allows direct comparison between them, even if a full inventory of epigeal invertebrates was not possible.

Pitfall trapping also potentially has different levels of effectiveness associated with the structure of surrounding vegetation. Although some pitfall catch may be due to arthropods falling off vegetation rather than being strictly epigeal, many target taxa such as the Araneae may not even encounter the traps if they are up above ground level in the vegetation (Meek *et al.* 2002). Except for the Linyphiidae, the Araneae are generally not well represented in sweep net catches (Standen 2000). Indeed, in this study, no Lycosidae were caught in sweep nets, but Araneidae, Linyphiidae and

Tetragnathidae were present. Varying crop, headland and comparison site vegetation architecture made invertebrate sampling by sweep net difficult to standardise. The most difficult habitat to sample in this way was the *Miscanthus* once it was above head-height. Every effort was made to sweep through the canopy in a similar way to the *Phalaris*, but the length of high sweep needed in the *Miscanthus* differed from that required in the *Phalaris*.

With nearly 15,000 invertebrates to identify from the various trapping techniques, many man-hours were required for the task, and it was split between two people. The author identified pitfall trap and sticky trap specimens, while an assistant dealt with the sweep net and pan trap catches. There is always a subjective element to the interpretation of identification keys, particularly for the more difficult taxa, and it is quite possible that interpretative differences existed between the two personnel. However, the fact that just one individual identified all the samples from each trapping method, the catches are directly comparable between habitats.

The decision to classify invertebrates by size was made when the pitfall specimens had already been counted. In retrospect, these pitfall specimens should also have been subject to classification by size, which could have given a useful indication of the food value of the individuals trapped, particularly the coleopterans, which had the widest range of sizes (1 mm - >15 mm).

Vegetation surveys were a relatively simple task performed reasonably quickly and with the resulting data available immediately and no requirement to spend long hours in the laboratory sorting and identifying specimens, as for the invertebrates. However, not every single weed species in the crops was sampled in the quadrat area. Within the *Phalaris* crop at site LL, corn mint *Mentha arvensis* was found growing in several patches, but did not occur within any of the quadrats surveyed. This is an arable weed that has shown significant decreases in distribution in

Europe between 1957 and 2000 (Baessler & Klotz 2006) and is a species of local concern (Byfield & Wilson 2005).

Some of the plot sizes surveyed were relatively small (0.25 ha) in comparison with the potential sizes of commercial crops fields. In *Miscanthus*, in particular, moving through the crop was particularly difficult once it was taller than head height. The furthest distance into the crop that was surveyed was 50 m, which in itself was sometimes a challenge. It was very easy to become disorientated or lost, and even with a tape measure, it was not always possible to proceed exactly 50 m in a straight line when having to negotiate the clumps of stems and those that had fallen at an angle. The sharp edges of leaves could be injurious to exposed human skin and eyes, and the springy nature of the stems meant that they could whip sharply back if anyone else was moving through the crop, thus making movement through the *Miscanthus* potentially hazardous! For these reasons, the transect positions were established immediately after harvest when only stubble was present. As the crop grew, a path to each transect was marked with string, and the same route through the crop was used at each survey. Whilst it would have been preferable to survey deeper into the crops in case an edge effect of more than 50 m was present (e.g. Holland *et al*. 1999), the practicalities of doing this both in terms of the additional time and manpower required made this impossible.

2.4.10 General conclusions

Quantifying invertebrate communities in an agroecosystem is a time-consuming and difficult task due to the wide variety of microhabitats and forms of locomotion used by both epigeal and aerial taxa. The tall and dense architecture of *Miscanthus* only adds to these difficulties. However, results from the invertebrate and weed compositional data reported in this chapter suggest that a wide diversity of taxa persist within the biomass crops, even if this diversity is not quite as extensive as that found in the headlands. The lack of soil disturbance caused through utilising a

perennial biomass grass crop is likely to enhance breeding opportunities for certain invertebrates and for this reason, the biomass crops are likely to be beneficial in comparison with annual crops. Utilising a biomass grass crop field structure that includes hedgerows and an uncultivated field margin as an overall habitat provides good resources for higher trophic levels as well as aiding the provision of ecosystem services through supporting pollinators and natural enemies.

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Bug guide http://bugguide.net/node/view/15740

Diptera info: http://www.diptera.info/photogallery.php

Dipterists' forum: http://www.dipteristsforum.org.uk/index.php

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CHAPTER 3

BIOMASS GRASS CROPS AS NEW AGRICULTURAL HABITAT FOR SMALL MAMMALS

Abstract

The advent of perennial biomass grass crops in the agricultural landscape has created a very different habitat to that previously provided by traditional annual crops, or by grazed pasture. As yet there is a paucity of data available in terms of potential effects on small mammals within the agricultural landscape.

The aim of this chapter was therefore to assess the impacts of growing the biomass grass crops *Miscanthus* x *giganteus* and *Phalaris arundinacea* on small mammal diversity and abundance in comparison with adjacent arable crops and grassland. Live trapping was performed over two years in biomass grass crops, their field margins and adjacent comparison sites at four sites across mid and west Wales and Herefordshire.

Eight species of small mammals were found within the biomass crops, including a priority species, the harvest mouse, and also the water shrew. Wood mice were ubiquitous in all areas surveyed. Within the biomass crops, *Miscanthus* contained higher small mammal abundance and the *Phalaris* a greater biodiversity. Hedges contained the highest overall abundance of small mammals, but a less diverse assemblage than in the *Phalaris*. Spring harvest of the *Phalaris* biomass was more beneficial to small mammals than an autumn harvest. The standing biomass crops prior to harvest provided winter habitat and cover not usually found on farmland where annual crops or grass are grown. In conclusion, both biomass grass crops were well utilised by an abundant and diverse range of small mammals.

3.1 Introduction

3.1.1 Small mammal species

The small mammals commonly found on agricultural land in mainland Britain belong to three main families. Family Muridae (Order: Rodentia) comprises mice including the wood mouse *Apodemus sylvaticus* (L.), yellow-necked mouse *Apodemus flavicollis* (Melchior) and harvest mouse *Micromys minutus* (Pallas). Family Cricetidae (Order: Rodentia) contain the field vole *Microtus agrestis* (L.) and bank vole *Myodes glareolus* (Schreber). The Family Soricidae (Order Eulipotyphla, formerly Insectivora) comprise the shrews, including the common shrew *Sorex araneus* (L.), pygmy shrew *Sorex minutus* (L.) and water shrew *Neomys fodiens* (Pennant).

For the purposes of this study, only the small mammal species listed above (<50g) are discussed.

3.1.2 Distribution, abundance and diet

Muridae

The wood mouse is an abundant, widespread, common species (Figure 3.1) which is highly adaptable to a range of dry habitats. It has a varied diet, comprising animal matter, live and dead invertebrates, alongside plant material including buds, fruits, leaves and seeds, as well as fungi (Flowerdew & Tattersall 2008). Its populations follow a seasonal cycle, where peak numbers occur in autumn/winter and the lowest numbers in spring and early summer (Kotzageorgis & Mason 1997; Harris *et al*. 1995). Its close relative, the yellow-necked mouse, is a locally common species in southern Britain (Figure 3.2). It mainly inhabits mature deciduous woodland but is also found in hedgerows and farmland (Harris *et al*. 1995). It has a similar diet to the wood mouse, but appears to specialise on tree seeds rather than herbaceous weed seeds (Marsh & Montgomery 2008).

Although the harvest mouse has a limited distribution in Britain, occurring mainly in the Midlands, southern England and parts of coastal Wales (Figure 3.3) it can be abundant in the areas where it occurs. It is thought to have declined in number in recent years (Flowerdew 2004) and is listed as a UK Biodiversity Action Plan priority species, although it is not currently protected by law (Mitchell-Jones *et al.* 2008). It is typically associated with areas of dense monocotyledons such as cereal fields, reedbeds and rough grassland (Harris *et al.* 1995). Harvest mouse diet is broad and includes invertebrates, grains, seeds, fruits, leaves, moss, fungi and roots (Trout & Harris 2008).

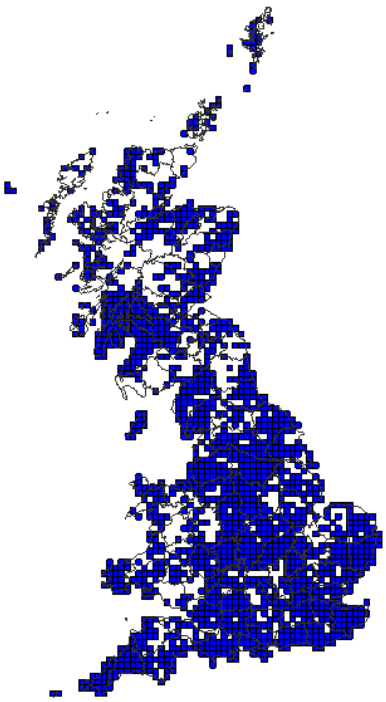

Figure 3.1 10km distribution of the wood mouse *Apodemus sylvaticus* in Great Britain. Shaded boxes represent presence in 10km squares. Data source: National Biodiversity Network Gateway http://data.nbn.org.uk © Crown copyright and database rights 2011 Ordnance Survey [100017955].

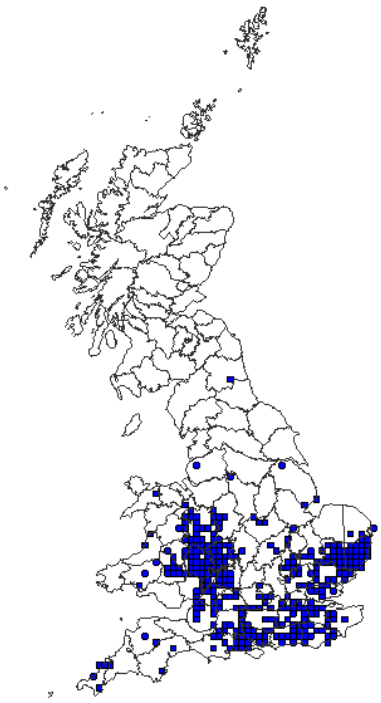

Figure 3.2 10km distribution of the yellow-necked mouse *Apodemus flavicollis* in Great Britain. Shaded boxes represent presence in 10km squares. Data source: National Biodiversity Network Gateway http://data.nbn.org.uk © Crown copyright and database rights 2011 Ordnance Survey [100017955].

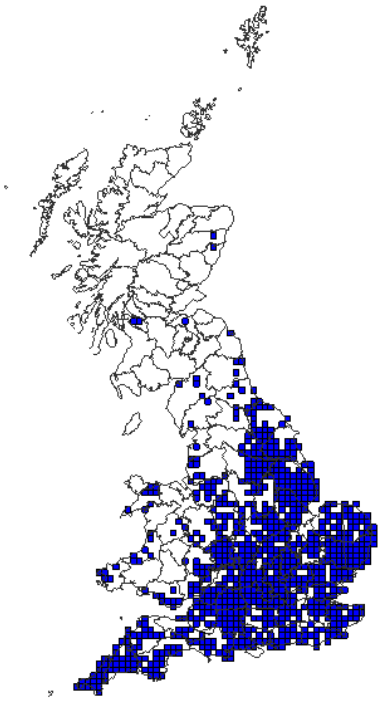

Figure 3.3 10km distribution of the harvest mouse *Micromys minutus* in Great Britain. Shaded boxes represent presence in 10km squares. Data source: National Biodiversity Network Gateway http://data.nbn.org.uk © Crown copyright and database rights 2011 Ordnance Survey [100017955].

Cricetidae

The bank vole is considered to be common and is found throughout mainland Britain (Figure 3.4). It primarily occurs in mature, mixed deciduous woods containing a thick field layer, but can also be found in hedges and young tree plantations (Harris *et al.* 1995). Although its diet is mainly herbivorous, it includes similar items to the wood mouse but with a higher proportion of leaf matter and invertebrates (Shore & Hare 2008).

The field vole (Figure 3.5) is abundant in areas where ungrazed, rough grassland occurs, although it has also been recorded in hedgerows, moorland and woodlands (Harris *et al.* 1995). Its diet is completely herbivorous, consisting of leaves, stems and some moss (Lambin 2008). Despite cyclic population explosions and crashes (Huitu *et al.* 2004), they are considered to be extremely abundant and are important prey source for predators such as the barn owl *Tyto alba* (Love *et al.* 2000).

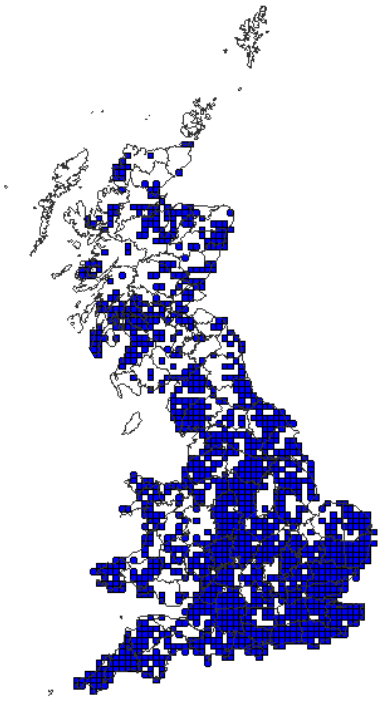

Figure 3.4 10km distribution of the bank vole *Myodes glareolus* in Great Britain. Shaded boxes represent presence in 10km squares. Data source: National Biodiversity Network Gateway http://data.nbn.org.uk © Crown copyright and database rights 2011 Ordnance Survey [100017955].

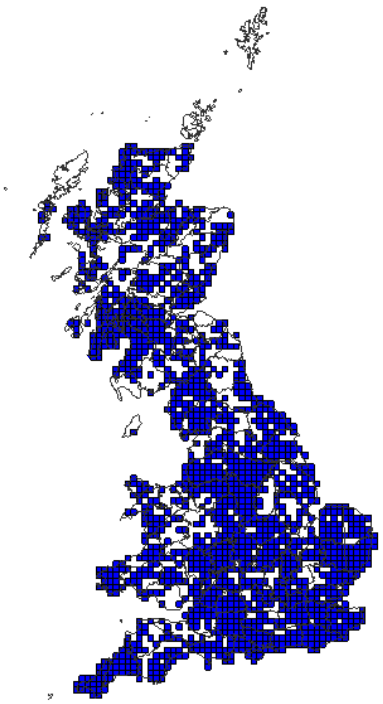

Figure 3.5 10km distribution of the field vole *Microtus agrestis* in Great Britain. Shaded boxes represent presence in 10km squares. Data source: National Biodiversity Network Gateway http://data.nbn.org.uk © Crown copyright and database rights 2011 Ordnance Survey [100017955].

Soricidae

The common shrew and pygmy shrew are abundant in mainland Britain (Figures 3.6 and 3.7), inhabiting areas containing low vegetation such as hedges, woods and dense grass.

They are opportunistic predators, particularly favouring prey from the Orders Coleoptera, Araneae, Opiliones and Isopoda, as well as insect larvae (Churchfield 1982). Other prey items include adult flies, slugs and worms, and small quantities of plant material and seeds may also be taken (Churchfield & Searle 2008). There is thought to be very little overlap in the diet of the pygmy and common shrew. However, invertebrates active in the litter surface are targeted mainly by the pygmy shrew, which preys on smaller individuals than the common shrew. The common shrew, in turn has a larger proportion of earthworms, slugs and snails in its diet and thus, interspecific competition for food resources is reduced (Pernetta 1976). In large numbers, shrews can significantly reduce the numbers of large

invertebrates in grassland communities (Churchfield *et al*. 1991) and this may be beneficial to man if pest species are amongst the invertebrates consumed.

The water shrew is widely distributed throughout the UK (Churchfield & Searle 2008; Figure 3.8) and is usually associated with fast-running, pollution-free streams and rivers. It has been recorded in woodland and on agricultural land, but this is thought to be a transient presence as it travels between preferred habitats (Harris *et al.* 1995). Its diet comprises a range of both terrestrial and aquatic invertebrates, small aquatic vertebrates and amphibians, and it can survive away from water on a terrestrial invertebrate diet (Churchfield 2008). All shrews have a high metabolic rate and require a daily consumption, from 50% of their body weight (water shrew) to 125% (common shrew) or 150% (pygmy shrew) in order to avoid starvation (Churchfield & Searle 2008). Lifespan is short, with high mortality rates in autumn. For some time, the reason for this was unknown, until the naturalists of a century ago concluded that it was nothing more than old age causing the deaths (Moffat 1910). All the above shrew species are listed on Schedule 6 of the Wildlife and Countryside Act 1981, which makes it illegal to kill them or take them by certain methods. Despite this, if activities are undertaken for scientific, educational, marking or other restricted purposes, licensing is available (Mitchell-Jones *et al*. 2008).

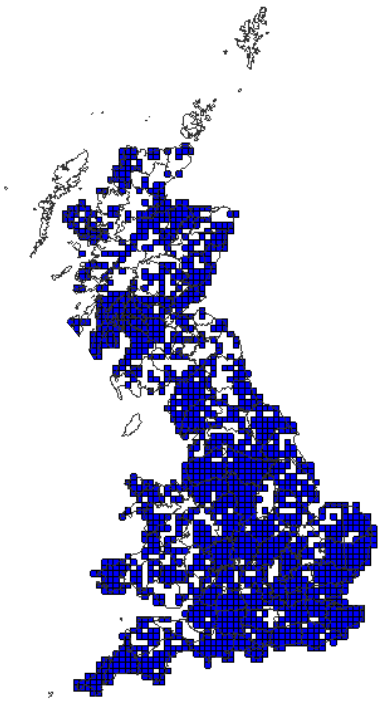

Figure 3.6 10km distribution of the common shrew *Sorex araneus* in Great Britain. Shaded boxes represent presence in 10km squares. Data source: National Biodiversity Network Gateway http://data.nbn.org.uk © Crown copyright and database rights 2011 Ordnance Survey [100017955].

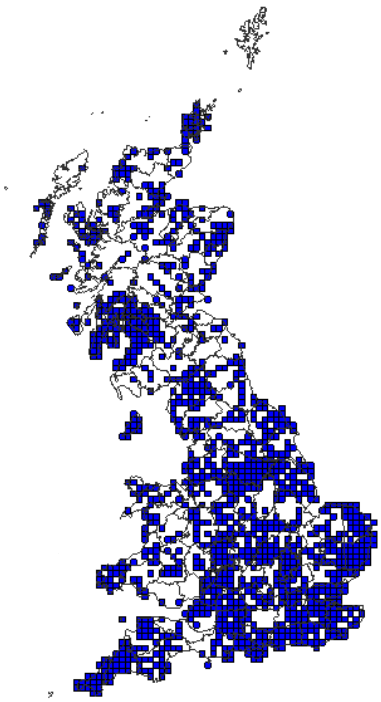

Figure 3.7 10km distribution of the pygmy shrew *Sorex minutus* in Great Britain. Shaded boxes represent presence in 10km squares. Data source: National Biodiversity Network Gateway http://data.nbn.org.uk © Crown copyright and database rights 2011 Ordnance Survey [100017955].

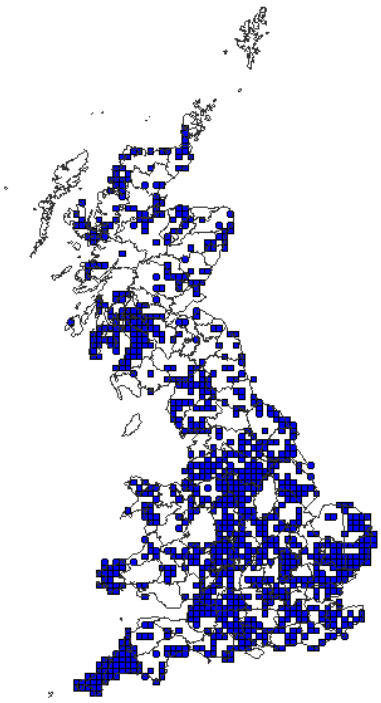

Figure 3.8 10km distribution of the water shrew *Neomys fodiens* in Great Britain. Shaded boxes represent presence in 10km squares. Data source: National Biodiversity Network Gateway http://data.nbn.org.uk © Crown copyright and database rights 2011 Ordnance Survey [100017955].

3.1.3 Population dynamics

Populations of small mammals are prone to fluctuations, both seasonally each year and also on a 3-5 year cycle (Huitu *et al.* 2004; Korpimäki & Norrdahl 1998). The cyclic fluctuations can result in population crashes, even when environmental conditions are conducive for breeding. The mechanisms underlying this are poorly understood, although the influence of predators is thought to be significant (Korpimäki & Norrdahl 1998). For example, Korpimäki & Norrdahl (1998) found that in a year when vole populations crashed elsewhere, an area of experimental predator removal did not show the same population decrease, leading the authors to conclude that predator presence was an important factor, if not the sole predictor of population change.

Seasonal population peaks vary between species: Huitu *et al.* (2004) found that common shrew populations peaked earlier in the year than field voles, which were followed by peaks in bank vole numbers. Some interspecific effects were also seen,

with common shrew population growth appearing to be negatively affected by rodent density in peak vole years, and bank voles showing a temporary negative effect where field vole density was increasing (Huitu *et al.* 2004). Kotzageorgis & Mason (1997) reported seasonal variations in trapping success in hedgerows: harvest mice were only caught in winter, wood mice numbers increased in autumn/winter and declined in spring, bank voles were most likely to be caught in spring/summer and common shrew numbers peaked in summer, declining rapidly in autumn. No obvious pattern was seen for yellow-necked mice. However, yellow-necked mice are often found in buildings over the winter (Marsh & Montgomery 2008) and this may influence their numbers in their usual habitats at this time of year. Another trapping study in wet meadows revealed seasonal peaks in autumn and winter, with the lowest numbers occurring in spring and summer for the 10 small mammal species caught (Schmidt *et al.* 2005). Studies of barn owl diet through pellet analysis also show seasonal variation in small mammals consumed. Field voles formed a major part of the diet through autumn and winter, but when their numbers decreased in spring and summer, *Apodemus* spp. were consumed in greater numbers (Love *et al.* 2000).

3.1.4 Predators

Small mammals form an important part of the diet of many larger animals.

Birds

Barn owl pellets have been shown to contain remains of all eight small mammal species mentioned above (Love *et al.* 2000). Other avian small mammal specialist predators include the tawny owl *Strix aluco*, long eared owl *Asio otus*, short eared owl *Asio flammeus*, kestrel *Falco tinnunculus* and great grey shrike *Lanius excubitor* (Karlsson 2007; O'Mahony *et al.* 1999; Korpimäki 1985). Crows *Corvus* spp., magpies *Pica pica* and even pheasants *Phasianus* spp. may include small mammals in their diet (Trout 1978).

Reptiles and amphibians

Small rodents (and particularly their young) are known to be preyed on by adders *Vipera berus* (Shore & Hare 2008; Aitchison 1987) and even by toads (Harris 1979).

Mammals

In a study of twelve forested areas, red fox *Vulpes vulpes* scats contained the full range of 100% small mammal remains to none at all. Where small mammal remains were found, they predominantly consisted of field voles, the proportion of which within the diet was negatively associated with the availability of roe deer *Capreolus capreolus* carrion (O'Mahony *et al.* 1999). Similarly, high proportions of *Microtus* voles were found in fox scats in an agricultural area of Finland (Dell'Arte *et al.* 2007). It is possible that in sheep-grazed areas, the availability to foxes of ovine placenta at lambing time will reduce their small mammal consumption (FM Slater pers. comm).

Other mammalian predators include the domestic cat *Felis catus* (Woods *et al.* 2003), badger *Meles meles*, American mink *Mustela vison*, stoat *Mustela erminea* (O'Mahony *et al.* 1999), weasel *Mustela nivalis* and European polecat *Mustela putorius* (Macdonald & Barrett 1993).

3.1.5 Feeding ecology on agricultural land

The small mammal species included in this study have a range of dietary habits: from herbivorous voles and insectivorous shrews to generalist mice, although foraging behaviour depends on both the habitat in which they live and seasonality. Wood mice living on agricultural land have a varied diet, consuming animal matter, weed seeds and grains, whereas bank voles select more green plant matter (Abt & Bock 1998). When surveyed in wheat and barley fields, wood mice showed a preference for wheat, whereas common voles *Microtus arvalis* showed no preference between crops (Heroldova *et al.* 2008). Both these findings were

supported by laboratory feeding experiments (Heroldova *et al.* 2008). Green (1979) reported that the majority of wood mouse diet from April to June comprised weed seed and flowers, but changed to cereal endosperm from September to March. There is also evidence that wood mice, on a microhabitat scale, respond to patches of favoured weed seeds within an otherwise relatively homogenous area of arable crops (Tew *et al.* 2000).

Favoured prey items of common shrews, such as beetles, worms, snails and isopods, are taken where possible, regardless of their abundance, whereas a diet of less favoured prey such as centipedes (Chilopoda), spiders (Araneae) and insect larvae is only taken when these taxa are available in high numbers (Churchfield 1982).

3.1.6 Agri-environment schemes, set-aside land and new woodland subsidies

Agri-environment schemes were originally introduced to the UK in the late 1980s as a way of trying to enhance biodiversity through adoption of more "environmentally friendly" farming practices. Set-aside (a proportion of land taken out of arable production for a minimum of one year) was introduced under reforms of the Common Agricultural Policy (CAP) by the European Commission in 1988 as a means of reducing overproduction of cereals (Macdonald *et al.* 2007). The scheme became compulsory in 1992 and therefore gave further potential for increasing biodiversity, even though this had not been the primary aim (Macdonald *et al.* 2007). Compulsory set-aside was suspended in 2008, in response to fears about rising wheat prices, after flooding affected harvests, although some land is still classed as set-aside as a requirement of certain Environmental Stewardship options (DEFRA 2009). Many of the studies cited here (e.g. Macdonald *et al.* 2007; Askew *et al.* 2007; Tattersall *et al.* 1999, 2000, 2001, 2002) were undertaken during the existence of set-aside and therefore the UK rules pertaining to it are shown below for clarification (Table 3.1).

Table 3.1 The time-spans within which certain actions were required to be undertaken in order to comply with set-aside rules (DEFRA 2006).

Dates	Action required
From 15th January	No harvest of crops or grazing on the set-aside. By this time, green cover needs to be established through either sowing wildlife cover crops or grasses, or by allowing natural regeneration.
1 March – 15 July	Operations on set-aside land to be avoided in order to minimise potential harm to nesting birds and other wildlife
15 April	Earliest date on which non-selective herbicides may be used
15 July – 15 August 15 July – 31 August	Compulsory cut of green cover OR Compulsory destruction of green cover
31 August	End of set-aside period

A study of the methods of set-aside establishment using different seed mixes (one with a species-rich grass and forb mix and the other with a simpler mix of grass and clovers) found that wood mice preferred the species-rich areas, even though the sward was shorter and therefore provided less cover (Tattersall *et al.* 1999). In a further study (Tattersall *et al.* 2000), the use of set-aside by field voles was examined. No field voles were caught in the plots until 9 months after establishment, and even then, they were caught in low numbers and were assumed to be transient in the plot. However, from 20 months after establishment of the set-aside, field vole numbers steadily increased, indicating an expanding resident population. Subsequent to this (2-9 year old set-aside), field vole abundance was more closely related to high proportions of grass and litter than the increasing age of the plot (Tattersall *et al.* 2000).

A further agri-environment option is to leave uncultivated margins or headlands around an arable field, usually 2 m, 6 m or 20 m in width. Bank voles and common shrews were found in higher numbers in a grassy 3 m margin than in conventional fields where the crop was sown right to the edge (Shore *et al.* 2005). However, in the same study, wood mice showed no preference and field voles were only caught

infrequently, possibly due to the short time-span of the newly established margins (Shore *et al.* 2005). Askew *et al.* (2007) found that in 2 m margins, sward height correlated positively with small mammal abundance and that cutting the margins every 2 – 3 years rather than annually resulted in higher overall abundance as well as greater species richness of small mammals.

The Welsh Assembly Government (WAG) will introduce a new agri-environment scheme, "Glastir" from 2012, which replaces the previous four schemes ("Tir Gofal", "Tir Cynnal", "Tir Mynydd" and the Organic Farming Scheme). This is intended to produce payments to farmers in return for delivery of specific environmental goods, focusing on priority issues identified under the CAP Healthcheck Agreement in 2008, as well as important issues relating to climate change. These are stated to be:

- "Managing soils to help conserve our carbon stocks.
- Improving water quality.
- Managing water to help reduce flood risks.
- Conserving and enhancing biodiversity.
- Managing landscapes and historic environment.
- New opportunities to improve public access to the countryside."

(WAG 2010)

Another important part of the scheme comes under the Glastir "All-Wales Element" in which further funding is available under the Agricultural Carbon Reduction and Efficiency Scheme (ACRES). Grants will be made available for certain forms of energy generation including biomass boilers, although at present, the target fuel for these is home-produced woodchip (WAG 2010).

Glastir prescriptions relevant to small mammals on agricultural land include:

- Creation of wildlife corridors using shrubs, trees and rough grass margins

- Allowing field corners of improved land to revert to scrub and rough grassland
- Creation of rough grass margins along cereal crop fields
- Sowing of wildlife cover crops rich in seed resources (WAG 2010).

Further schemes exist, under different guises in England, Wales and Scotland, in which subsidies are also available for newly planted woods on farmland.

3.1.7 Arable land

Within an arable landscape, there is potential for a wide variety of crops to be grown: from cereals such as wheat, maize, oats and barley, to oilseed rape, potatoes, soft fruit and energy crops. Most previous small mammal studies have concentrated on cereal crops. Todd *et al.* (2000) radio-tracked wood mice on winter-sown arable crop fields in both winter and summer. In winter, preference for habitats (relative to their availability) was ranked hedgerow > oil-seed rape > barley > wheat. The strongest preference for the hedgerow in winter, was thought to be a result of changed foraging behaviour during winter, when predation risk from avian predators was higher in exposed crop fields (Todd *et al.* 2000). Within the cereal fields, the preferences were thought to reflect the marginally higher sward in the oil-seed rape and the availability of beech masts and acorns in a wood adjacent to the oil-seed rape field. Summer habitat preference relative to availability ranked hedgerow > wheat > barley > oil-seed rape, although in terms of habitat availability, hedgerow was a rare resource in relation to the area of crop fields, and the wood mice tended to spend the summer in the crops (Todd *et al.* 2000). Their apparent avoidance of oil-seed rape fields may have been due to the dense sward shading-out weeds and reducing other potential food sources within the crop field (Todd *et al.* 2000). When habitat preference of wood mice in arable fields was examined in finer detail, it was found that areas in which they spent the most time contained less bare earth and greater quantities of non-crop food plants than areas where they

were only recorded as transient. These aspects of microhabitat were deemed to be more important to their foraging decisions (and hence their overall habitat choice) than the particular type of crop monoculture (Tew *et al.* 2000).

3.1.8 Hedges and woodlands

Linear features such as hedgerows have generally been thought to provide a vital corridor between habitats, particularly for small mammals. For example, species such as the dormouse preferentially stay in corridors such as hedgerows, rather than cross gaps in order to reach another patch of appropriate woodland habitat (Bright 1998). Despite such evidence of hedgerows being used as dispersal corridors, there is relatively little direct evidence that they contribute to maintaining woodland fauna in fragmented habitats (Davies & Pullin 2007). Tattersall *et al.* (2004) found that woodland plots connected with hedgerows (and therefore allowing immigration) were more likely to contain wood mice than plots which were not well-connected. On pastoral land, both wood mouse and bank vole density were determined by hedgerow connectivity, and a rough ungrazed margin fenced off from the grazed field contained higher densities of field voles (Gelling *et al.* 2007; Butet *et al.* 2006). Tattersall *et al.* (2002) found that bank voles preferred linear habitat such as field margins and set-aside compared with non-linear blocks of similar habitat, but found no such effects for field voles, wood mice or common shrews. Harvest mice also showed a preference for field edges in arable land (Moore *et al.* 2003). In a comparison of three French agricultural landscapes differing in intensification levels, hedgerows in the most highly intensified landscape contained higher small mammal biomass (but lower diversity) than the less intensified areas (Michel *et al.* 2006).

Management of hedgerows can dramatically affect the small mammal populations living them. Wood mice were found to be robust in their preference for hedge habitat in the autumn, even after the hedges were cut back, but yellow-necked

mice abandoned the hedgerow completely after this intervention (Kotzageorgis & Mason 1997). The extent of ground cover also affected presence of bank voles and common shrews: this was partly related to hedgerow age, as both newly established and mature unmanaged hedges had relatively sparse ground vegetation (Kotzageorgis & Mason 1997).

Where new woodlands were planted under the subsidised scheme previously described, Moore *et al.* (2003) reported greater abundance and diversity of small mammals within the new plantations compared with hedgerows and agricultural land. Harvest mice and wood mice were the most abundant small mammal species within the new woodland.

3.1.9 Grazing and agricultural practices

The different habitat requirements of small mammal species mean that species richness, abundance and community composition will vary according to the height, structure and type of vegetation available (Moro & Gadal 2007). All successional stages of grassland vegetation are used by most small mammals, although some strong habitat preferences exist, such as harvest mice in ruderal vegetation and wood mice in late seral stages, (Churchfield *et al.* 1997).

Most small mammals are at risk from avian predators where little vegetation cover is available and this promotes changes in foraging behaviour in *Microtus* spp. voles (Jacob & Brown 2000). The grazing of pastoral land at high intensity can result in a reduced small mammal biomass (Wheeler 2008; Schmidt 2005; Steen *et al.* 2005; Montgomery & Dowie 1993). Conversely, low grazing intensity by either cattle or sheep was found to have a positive effect on biomass and survival of small mammals compared with ungrazed plots; this was thought to be due to different sward heights creating a mosaic effect (Schmidt *et al.* 2005). However, Moro & Gadal (2007) found the opposite pattern, with no small mammals caught in sheep-grazed

open fields that lacked a field-edge habitat. Grazing by large herbivores not only reduces cover for small mammals, but may also create competition for food resources and disturbance through trampling (Torre *et al.* 2007; Flowerdew & Ellwood 2000). Moro & Gadal (2007) did, however, find higher densities of small mammals in wooded areas to which sheep had access, suggesting that lack of cover was the primary factor driving the low small mammal abundance in the sheep-grazed fields, rather than competition with sheep for food.

Agricultural management practices involving cutting or removal of vegetation may also have important effects on small mammals. The practice of mowing and leaving the cut grass *in situ* as a mulch, resulted in an increased vole population, suggesting that the cut, lying vegetation formed a conducive habitat (Jacob 2003). However, in an arable setting, although harvest itself did not affect wood mouse populations, removal of the crop cover led to emigration and increased mortality from predation, resulting in an overall 80% reduction in population levels (Tew & Macdonald 1993). A change in the practice of mowing vegetation around ditches in The Netherlands resulted in greater abundance and species richness of small mammals, when annual mowing was performed on only one side of the ditch each year, instead of both sides being mown at the same time. The resulting reedy habitat supported common voles, harvest mice and common shrews (Huijser *et al.* 2001).

3.1.10 Energy crops

In Britain, agricultural land is increasingly being used to grow perennial biomass energy crops, usually short rotation coppice willow or tall grasses. Land area planted with *Miscanthus* in the UK increased from 52 ha in 2002 to approximately 12,700 ha in 2009. In 1998, there were 200 ha short rotation coppice, which increased to 6,400 ha in 2009 (Thompson 2009). Much of the interest in tall perennial biomass grasses in the UK has centred around *Miscanthus* spp. and

Phalaris arundinacea. The agronomy, harvesting regime and use of these crops as fuel has been well studied and documented (Prochnow *et al*. 2009; Lewandowski *et al*. 2003; Price *et al*. 2003; Landström *et al*. 1996). Less well documented are some of the environmental impacts of growing these crops, in particular the effects on biodiversity. These biomass crops are being grown not only on arable land, but also on improved grassland, and the impact of this change of land use on native wildlife is uncertain. This has led to either speculation about - or modelling of -possible negative effects (Eggers *et al*. 2009; Anderson *et al*. 2004). Reasons cited for these concerns have predominantly been related to the introduction of a novel, non-native monoculture, potentially across wide areas of agricultural land (Anderson *et al*. 2004).

There is a current paucity of work concerning the diversity of small mammals in biomass crops. Fry & Slater (2009) found that the small mammal fauna of short-rotation willow coppice throughout Wales, UK was less diverse than the surrounding hedgerows and headlands, where a total of six species were caught (wood mouse, yellow-necked mouse, field vole, bank vole, common shrew and pygmy shrew). Despite this reduced species diversity, the willow crop contained nearly double the number of individuals found in the hedge and headland combined. This abundant, yet species-poor small mammal fauna of the willow crop was dominated by the wood mouse (Fry & Slater 2009).

Semere and Slater (2007a, b) investigated a broad range of organisms within *Miscanthus* and *Phalaris* crops in Herefordshire, UK up to three years after planting for a Department for Trade and Industry (DTI) contract. During that period, the authors reported the same six small mammal species as Fry & Slater (2009), but in both the cropped areas and field margins. Wood mice dominated in both areas, although the greatest numbers and diversity were found in the field margins. Due to the restricted terms of the contract no arable-land comparison plots were used,

so it is unknown how the diversity of small mammals caught within the biomass crops would have compared with those in a cereal crop. Despite this, it was suggested that the presence of weed vegetation in the biomass crops as well as the low input management and the large amount of standing dry matter over the winter would together increase the benefits for biodiversity in general (and small mammal diversity in particular) in comparison with traditional arable crops (Semere & Slater 2007a, b).

Tombs (2007, unpublished) used one night of trapping per month to investigate small mammal distribution in adjacent plots of mixed woodland, grazed pasture, *Miscanthus* and *Phalaris*, between January and July. The woodland contained the highest abundance of small mammals and the grazed area the lowest. Wood mice dominated in all areas, while the only clear preference for the biomass crops was shown by field voles, which were captured in higher numbers in *Phalaris*. In addition to habitat preferences, temporal effects were apparent, with abundance of bank voles and yellow-necked mice increasing over the duration of the study.

3.1.11 Aims

In view of the limited prior work, which was carried out on predominantly young biomass crops (<3 years since planting), the aims of this study were to test for differences in small mammal species abundance and community diversity, between established biomass crops (>3 years) and other grassland or arable crops found within close proximity of the biomass crops. The wider aim was to predict the impact on small mammal biodiversity of a shift to increased biomass crop production on agricultural land.

3.2 Materials and methods

3.2.1 (a) Year 1 surveys and sites

Four field sites in the UK, across Wales and the English border, comprising a total of four plots each of *Miscanthus* and *Phalaris* were included (see a more detailed description in Chapter 1). The two largest sites were in predominantly arable areas: site 'N' was surrounded by rotations of spring barley and fodder beet, whilst 'HM' was surrounded by crops of oats and blackcurrants. The remaining two sites 'LL' and 'PP' were in predominantly pastoral hilly areas, with surrounding fields grazed by sheep and cattle. Individual plot size ranged from 0.25 ha ('LL') to 8 ha ('HM'). All sites had a traditional field structure, of a boundary hedge separated from the crop by an uncultivated margin of between 2 and 6 m were present at all sites. Comparison plots took the form of a neighbouring field containing a non-biomass crop and included livestock-grazed grassland, set-aside and a blackcurrant field.

3.2.1 (b) Live trapping

Small mammal surveys were carried out at each field site for one night in each two-month period from April 2008 (immediately after harvest of above-ground material), to February 2009, after which the crops were mown again. One of the *Miscanthus* sites ('HM') was unexpectedly (to the author) mown early, in mid-December 2008 and the rhizomes were subsequently dug up, which brought an end to surveys there. Crops at site 'N' were mowed at the end of February 2009 and the scheduled small mammal survey for that month was therefore forfeited in order to be able to carry out a more extensive survey for harvest mice before the crop was lost.

Trapping was performed in calm, dry, mild conditions, which were needed for other fieldwork carried out at the same time (reported in Chapter 5). This, in addition to other logistical factors determined the order in which sampling was performed at each site. A thermometer was left at each site overnight, for the

duration that the traps were set, and maximum and minimum temperatures were recorded. Table 3.2 details the types of crops available at the different sites.

Table 3.2 Details of the trapping sessions at the different sites during Year 1 (2008-9).

Site	Crop types available	Times surveyed	No. of traps per site
LL	*Miscanthus* x1 and *Phalaris* x1	6	70
HM	*Miscanthus* x1 only	4	50
N	*Miscanthus* x1 and *Phalaris* x1	5	90
PP	*Miscanthus* x1 and *Phalaris* x2	6	110

Longworth live traps (Chitty and Kempson 1949), Penlon Ltd, Abingdon, UK were provisioned with mixed seed, hay and mealworms. They were set within each crop at a series of transects running parallel with the crop edge, at 10, 20 and 50 (where available) metres into the crop (Figure 3.9). Traps were also set in a transect in the middle of the uncultivated field margins (known as "headlands"). In comparison plots, a transect at least 20 m from the field boundary was established. Each transect contained 10 traps at a minimum distance of 2 m intervals. Traps were set in the evening, approximately 30 minutes before dusk and checked early the following morning (around 2 hours after sunrise) before being removed. Small mammals were identified to species only and released at the point of capture.

Figure 3.9 A Longworth trap set at the base of a clump of *Miscanthus* (left) and a captured wood mouse (right).

3.2.2 (a) Year 2 surveys and site

In Year 2, (2009-10), surveys were restricted to site 'N' and were intended to focus on the harvest mouse. Transects were originally laid at 20, 50 and 100 m from the north crop edge (Figure 3.2) as used in Year 1, into the *Miscanthus* (henceforth '*Miscanthus* 1') and *Phalaris* crops. After the first survey, it became apparent that in order to assess the wider distribution of small mammals throughout the field, trap lines needed to be increased to include a transect nearer to the south hedge (180 m, instead of the 50 m transect), and the same distance transects were also established in the slightly younger *Miscanthus* plot ('*Miscanthus* 2') adjacent to the east side of the *Phalaris*.

A line of traps was also positioned in each of the hedgerows (rather than the headlands) surrounding the biomass field, and also on the opposite side of the north hedge in the barley field. For the first three surveys, additional trap transects were set in the crop and hedgerow of the *Miscanthus* field ('*Miscanthus* 3') across the track from the main field. However, these were suspended after harvest in March as no harvest mice were trapped there during the time-span in which they were trapped in the main field, and the resulting spare traps were used to increase coverage of the main field as described above. Additionally, trap lines were set in adjacent fields of maize and spring barley, from when the crop had reached a height of approximately 20 cm, until harvested. In order to maximize access and minimize crop damage, these transects were located at 20 and 50 m from the edge of the crop and where possible, followed the "tram-lines" left by the passage of tractor wheels (see Figure 3.10 for transect locations).

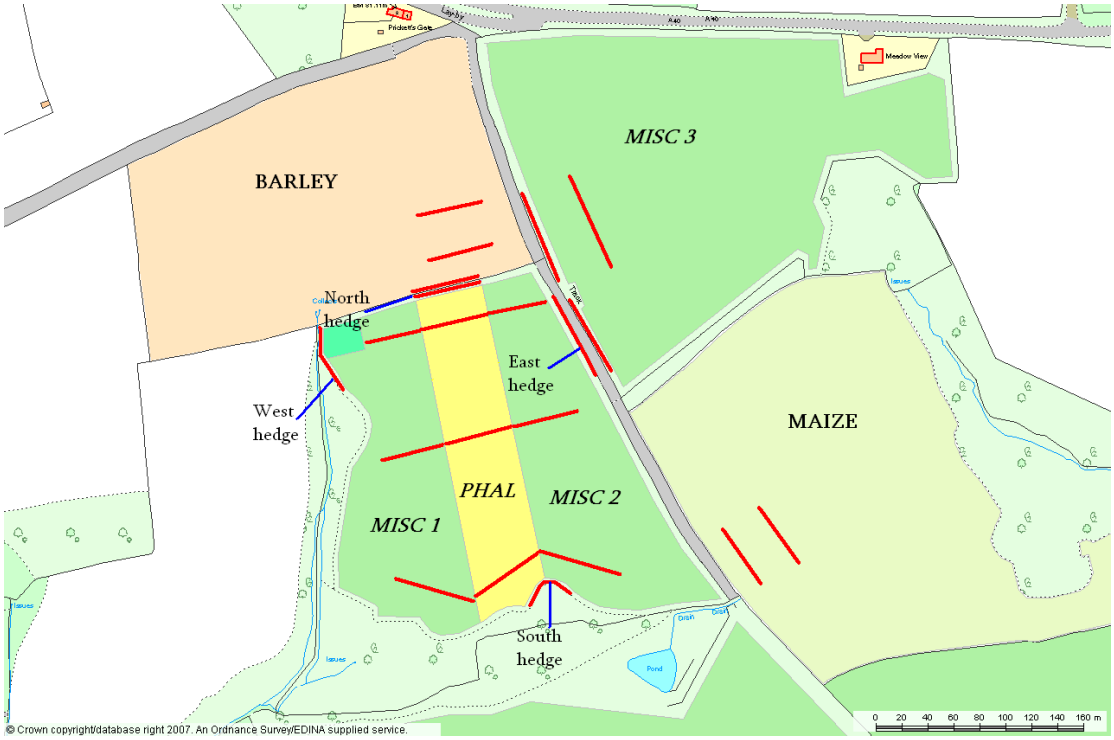

Figure 3.10 Positions of the transects (bold red lines) within the different crops at site 'N' in Year 2 (2009-10).

3.2.2 (b) Live trapping

Traps were provisioned as detailed previously (section 3.2.1(b)), but with the addition of pieces of carrot as a moisture source during hot weather. Traps in areas not already shaded by vegetation were covered with squares of hessian cloth in order to prevent overheating in the sun.

Ten traps per transect were used, with trapping performed for 48 hours at 1-month intervals (for dates see Table 3.3). Traps were checked at each dawn and dusk. Midday checks were also made through spring and summer until short daylight hours from late October 2009 to late January 2010 made this impracticable and unnecessary. All harvest mice captured were weighed, sexed and given a unique fur clip before release to allow subsequent recognition if re-trapped (see more detailed description in Chapter 4, section 4.2.3). Any other small mammals captured were identified to species only before being released at the point of capture.

Table 3.3 Dates of trapping sessions in Year 2 (2009-10) at site "N" and status of the various crops at those times.

Date	Comments
19-21 Feb 2009	Both crops intact
24-26 Feb 2009	Both crops intact
04-06 Mar 2009	*Miscanthus* 1 & 2 now stubble, *Phalaris* still standing
23-25 Mar 2009	*Phalaris* now stubble. Transects expanded to include 180 m in *Miscanthus* 1 & 2 and *Phalaris*
21-23 Apr 2009	
19-21 May 2009	
01-03 Jul 2009	Added barley 20 and 50 m transects, tripods in use throughout
04-06 Aug 2009	Added maize 20 and 50 m transects
02-04 Sep 2009	Barley now stubble
29 Sep -1 Oct 2009	
27-29 Oct 2009	Maize now stubble
24-26 Nov 2009	*Miscanthus* traps taken off tripods and placed at ground level as wind and crop movement causing traps to fall off
(05-07 Jan 2010)	*Intended survey not carried out due to extreme winter weather*
26-28 Jan 2010	*Miscanthus* 2 now stubble, *Miscanthus* 1 and *Phalaris* still standing – final survey
Feb 2010	Remainder of biomass crops harvested

Tripods were constructed from 1 m bamboo poles and wire, and included a sloping platform of plastic mesh approximately 40 cm above ground level. Once both cereal and biomass crops had reached a height of 50 cm, alternate Longworth traps within the crops were elevated on a tripod with the entrance in contact with the vegetation, in an effort to target harvest mice dwelling in the stalk zone (Figure 3.11).

Figure 3.11 Longworth traps suspended on tripods in *Phalaris* (left) and barley (right).

3.2.3 Vegetation and crop characteristics

Crop height was recorded at each survey during Year 1. Five crop stems in close proximity were selected at five points along each transect of each crop and the height to the topmost ligule was recorded. At the same five points within the transect, light readings were taken both above the crop and at ground level using a light meter (British Gas Energy Studies Measuring Instrument Mk2, Portec, Milton Keynes, UK). The ambient light reaching ground level was calculated as a percentage of the light reaching the top of the crop and this was taken to represent the extent of shading by the crop at ground level.

Every four months in Year 1 (commencing in April 2008), vegetation surveys were carried out. A 50 cm x 50 cm quadrat was placed at one end of the 20 m transect and then at a further four points equally spaced 4 m apart along the transect. Within each quadrat, percentage cover of crop, crop litter, other litter, bare ground, bryophytes and individual non-crop plant species were estimated visually. A further vegetation survey was carried out once in Year 2 (October 2009).

3.2.4 Data analysis

Data were analysed using the statistical package STATISTICA 9.1 (StatSoft Inc). Normality of data frequency distributions was checked using the Shapiro-Wilk test. Normally distributed data were analysed using Factorial or One-way Analysis of Variance (ANOVA) or t-tests. Where non-Gaussian distributions occurred, it was impossible to achieve normality using data transformations. In these instances, differences in small mammal abundance between the different crops, transects and time periods were tested using non-parametric Kruskal-Wallis tests.

As different sites and crops had different numbers of transects, comparisons between trapping periods were made using a calculation of numbers of individual animals per 100 trap-nights (TN). One TN represents one trap set for one night. Small mammal distribution was quantified by calculating the percentage of transects in which they were trapped.

Relationships between small mammal abundance, different species and crop characteristics were explored using Spearman's rank correlation and by Generalized Linear Models (GLM) and Canonical Component Analysis (CCA).

Shannon-Wiener Index and Simpson's Index of Diversity were calculated for the different sampling areas using an online calculator (Young 2009). In some analyses for Year 1, such as crop preference and seasonality, only data from the *Phalaris* crops mown in spring were included. This excluded one field at one site ('PP2'), which was mown in autumn and then grazed by sheep in November 2008.

In order to make Year 2 data directly comparable with Year 1 (where trapping was only performed for one night), only captures from the first night of trapping were included in general small mammal analysis. More detailed harvest mouse data is reported separately in Chapter 4.

3.2.5 Abbreviations

The following abbreviations are used in tables and figures for the different small mammal species: WM = wood mouse, YNM = yellow-necked mouse, HM = harvest mouse, FV = field vole, BV = bank vole, CS = common shrew, PS = pygmy shrew, WS = water shrew.

3.3 Results

3.3.1 Small mammal captures

Trapping dates in Year 1 and mean temperatures for those dates are shown in Table 3.4. A total of 21 trapping sessions across the four sites were carried out giving a total of 1730 trap nights (TN).

Table 3.4 Dates of small mammal trapping at the different sites in Year 1 (2008-9) and the mean temperatures at the sites measured on those dates. Site abbreviations as described in Section 1.8.

Trapping date	Sample period designation	Site	Mean temperature (°C)
11/04/08	April 2008	LL	5.9
17/04/08	April 2008	HM	11.5
25/04/08	April 2008	PP	11.0
08/05/08	April 2008	N	16.0
02/06/08	June 2008	HM	16.5
06/06/08	June 2008	PP	14.0
02/07/08	June 2008	LL	16.0
09/07/08	June 2008	N	17.0
06/08/08	August 2008	PP	18.0
15/08/08	August 2008	HM	15.0
19/08/08	August 2008	N	14.5
28/08/08	August 2008	LL	14.8
07/10/08	October 2008	PP	14.0
10/10/08	October 2008	LL	10.3
27/10/08	October 2008	HM	8.0
06/11/08	October 2008	N	10.5
18/12/08	December 2008	PP	7.5
19/12/08	December 2008	LL	3.5
27/01/09	December 2008	N	4.5
12/02/09	February 2009	PP	3.9
17/02/09	February 2009	LL	3.9

Year 1 surveys resulted in a total of 219 small mammal captures, giving a catch per unit effort (CPUE) of 12.7%. Eight species of small mammal were trapped as shown by site in Table 3.5 and by crop in Table 3.6.

Table 3.5 Total numbers of the different small mammal species trapped in Year 1 (2008-9) by site.

Site Species	HM	LL	N	PP	Total no. trapped
Wood mouse	10	43	31	59	143
Yellow-necked mouse	3	9	0	0	12
Harvest mouse	0	0	8	0	8
Bank vole	0	1	5	3	9
Field vole	1	4	7	21	33
Common shrew	0	7	3	2	12
Pygmy shrew	0	1	0	0	1
Water shrew	0	0	0	1	1

Table 3.6 Total numbers of the different small mammal species trapped in Year 1 (2008-9) by habitat.

Habitat Species	Comparison plots	Headlands	*Miscanthus*	*Phalaris*
Wood mouse	1	25	78	39
Yellow-necked mouse	0	7	4	1
Harvest mouse	0	0	2	6
Bank vole	0	4	2	3
Field vole	5	2	4	22
Common shrew	1	0	4	7
Pygmy shrew	0	0	0	1
Water shrew	0	0	0	1
Total	7	38	94	80

In Year 2 at site 'N', 550 animals were trapped during 1825 trap nights, giving a CPUE of 30.1% (see Table 3.7).

Table 3.7 Total numbers of small mammals trapped during one night at each sampling period in the different areas at site "N" in Year 2 (2009-10).

Habitat Species	Comparison plots (arable)	Hedges	*Miscanthus*	*Phalaris*	Total
Wood mouse	16	164	116	35	331
Harvest mouse	0	0	2	27	29
Bank vole	0	88	13	4	105
Field vole	1	7	0	2	10
Common shrew	0	29	15	9	53
Pygmy shrew	0	13	2	1	16
Water shrew	0	1	2	3	6
Total	17	302	150	81	550

Table 3.8 shows a breakdown of catches in the areas surveyed, shown as number trapped per 100 TN for both Year 1 and Year 2.

Table 3.8 Numbers of the different small mammal species captured per 100 TN (includes autumn-mown *Phalaris* 'PP2').

Year	Habitat	WM	YNM	HM	BV	FV	CS	PS	WS	Total
1	**Comparison**	**<1**	**0**	**0**	**0**	**3**	**<1**	**0**	**0**	**4**
2	Comparison	16	0	0	0	1	0	0	0	17
1	**Headland**	**6**	**2**	**0**	**1**	**<1**	**0**	**0**	**0**	**9**
2	Hedgerow	24	0	0	13	1	4	2	<1	49
1	***Miscanthus***	**15**	**1**	**<1**	**<1**	**1**	**1**	**0**	**0**	**18**
2	*Miscanthus*	20	0	<1	2	0	3	<1	<1	26
1	***Phalaris***	**7**	**<1**	**1**	**<1**	**4**	**1**	**<1**	**<1**	**14**
2	*Phalaris*	8	0	7	1	0.5	2	<1	<1	20

The percentage of transects per survey area in which the species was found over one year are shown in Table 3.9 and represented graphically in Figure 3.12.

Table 3.9 Distribution small mammal species in different crops/habitats in Year 1 (2008-9) and Year 2 (2009-10). Values shown are the percentage of transects in each survey area in which the species was trapped over the course of 1 year (excluding 'PP2' after it was harvested).

Year	Habitat	Total no. transects	WM	YNM	HM	BV	FV	CS	PS	WS	Total
1	**Comparison**	**20**	**5**	**0**	**0**	**0**	**15**	**5**	**0**	**0**	**15**
2	Comparison	10	90	0	0	0	10	0	0	0	17
1	**Headland**	**44**	**34**	**11**	**0**	**9**	**2**	**0**	**0**	**0**	**45**
2	Hedge	64	80	0	0	67	8	34	19	2	94
1	***Miscanthus***	**51**	**67**	**8**	**2**	**4**	**6**	**8**	**0**	**0**	**71**
2	*Miscanthus*	58	74	0	3	19	0	19	3	3	81
1	***Phalaris***	**51**	**39**	**2**	**8**	**6**	**24**	**12**	**2**	**2**	**65**
2	*Phalaris*	37	46	0	32	8	3	16	3	8	70

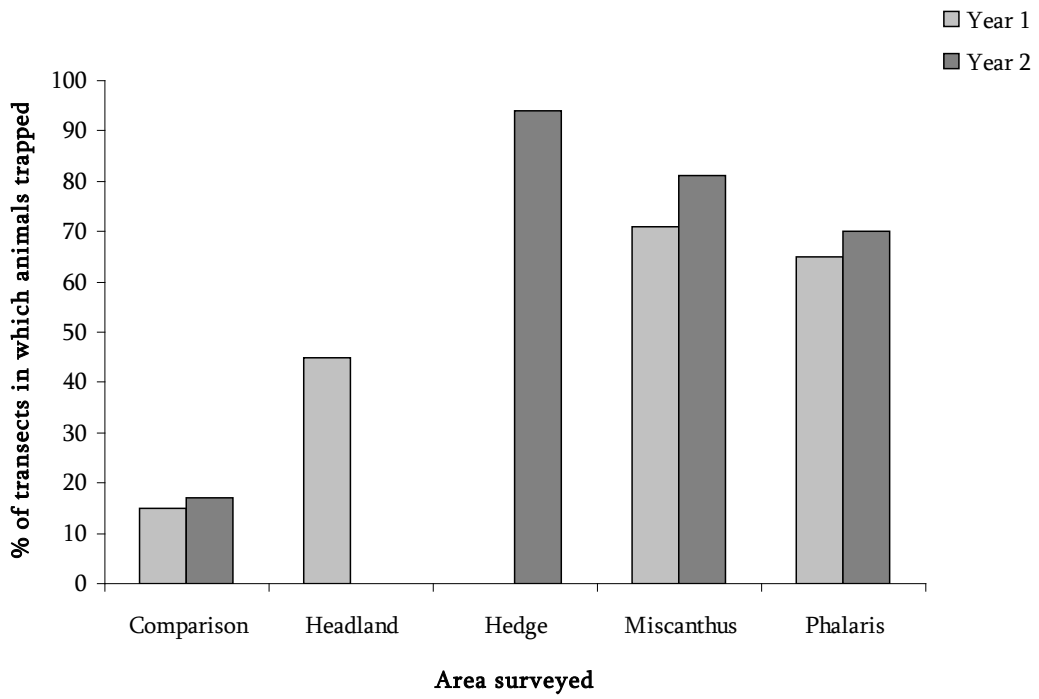

Figure 3.12 The percentage of transects in which small mammals were trapped in the various habitats in both Year 1 and Year 2.

3.3.2 Crop preference

Year 1

Small mammal catch totals for Year 1 were adjusted to exclude data from the autumn-mowed 'PP2' *Phalaris* as it was not representative of the management of all other *Phalaris* fields in the survey, which were left standing over winter and only mowed in late spring. Total small mammal catch was significantly different between survey areas (Kruskal-Wallis: H (3, N = 167) = 22.274 P <0.0001) in the order *Miscanthus* > *Phalaris* > headlands > comparison plots. Multiple comparisons (within an overall Kruskal-Wallis test) showed that counts in *Miscanthus* were significantly higher than in the headlands (P = 0.025) and the comparison plots (P <0.001), *Phalaris* counts were significantly higher than the comparison plots (P = 0.006) but no significant differences existed between the headlands and the comparison plots (P = 0.584) or between *Miscanthus* and *Phalaris* (Figure 3.13 and Table 3.10). A breakdown of the proportions of the different species of small mammals caught in the different areas is shown in Figure 3.14.

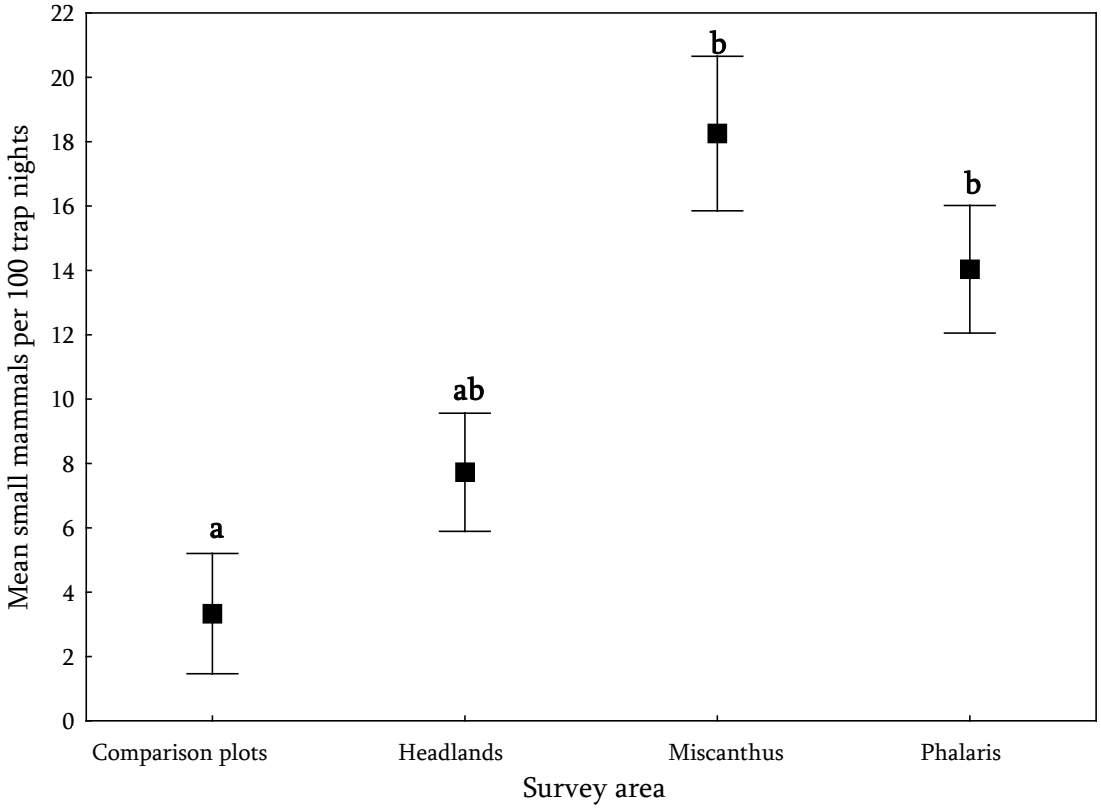

Figure 3.13 Mean number of small mammals captured per 100 TN in the different habitats trapped during Year 1. Bars represent ± 1 SE. Significantly different values are annotated with different letters; 'ab' = not significantly different from 'a' or 'b'.

Table 3.10 Pairwise comparison *P*-values (adjusted for multiple comparisons within an overall Kruskal-Wallis test) for significant differences in total small mammal numbers between the different areas surveyed in Year 1 (2008-9). * = significant result.

	Comparison plots	Headlands	*Miscanthus*
Headland	0.905		
Miscanthus	<0.001*	0.009*	
Phalaris	0.010*	0.221	>0.999

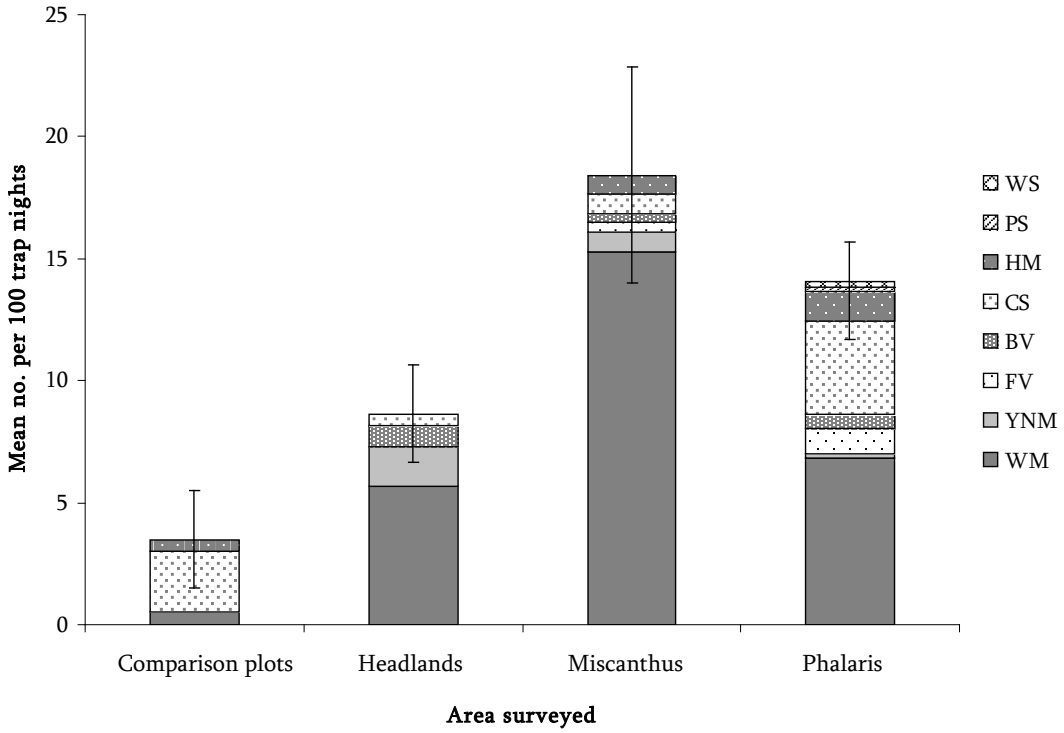

Figure 3.14 Relative abundance of the small mammal species trapped in each habitat across the four field sites in Year 1. Error bars represent ±1SE for mean no. of all species per 100 trap nights.

Year 2

Total small mammal catch was also significantly different between the areas surveyed in Year 2 (Kruskal-Wallis test: H (3, N=169) = 33.725, P <0.0001) with the hedges containing higher numbers than any other area (P <0.01) (Figures 3.15, 3.16 and Table 3.11). Mean catch per 100 TN per transect are shown in Appendix 1.

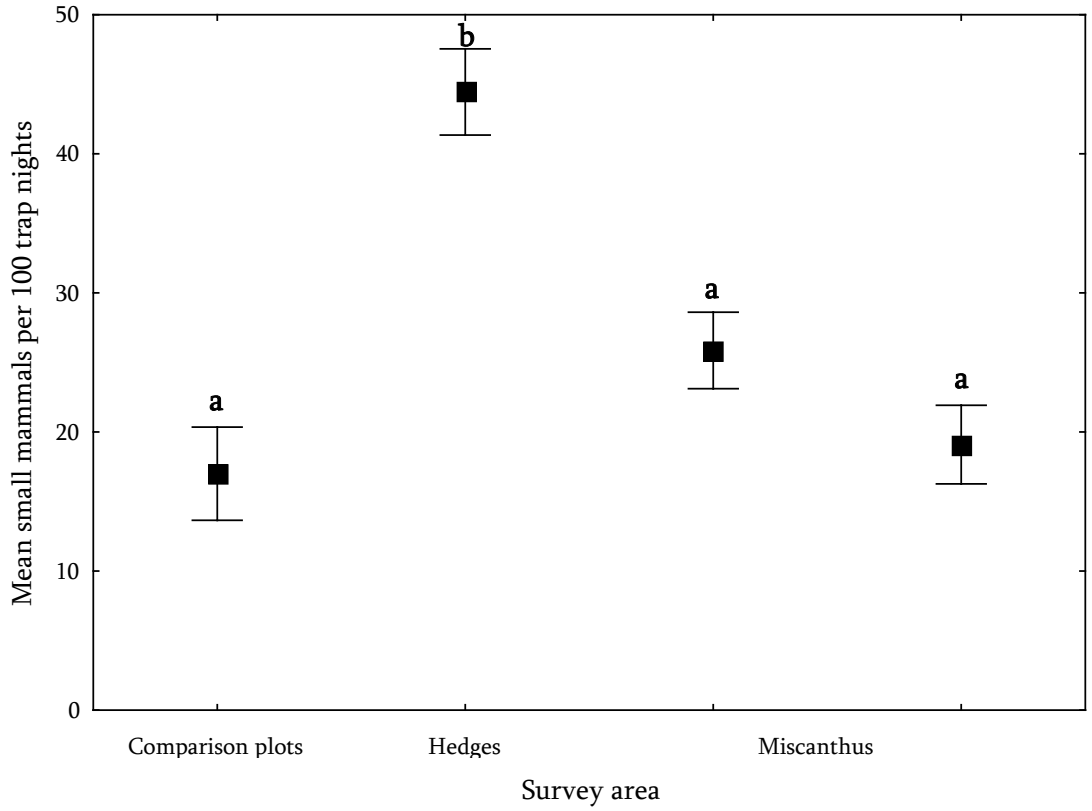

Figure 3.15 Mean number of small mammals captured per 100 TN in the different habitats surveyed during Year 2. Bars represent ± 1 SE. Values annotated with different letters are significantly different.

Table 3.11 Pairwise comparison *P* values (adjusted for multiple comparisons within an overall Kruskal-Wallis test) for significant differences in total small mammal numbers between the different areas surveyed in Year 2 (2009-10). * = significant result.

	Comparison plots	Hedges	*Miscanthus*
Hedges	0.006*		
Miscanthus	1.000	0.001*	
Phalaris	1.000	<0.001*	0.885

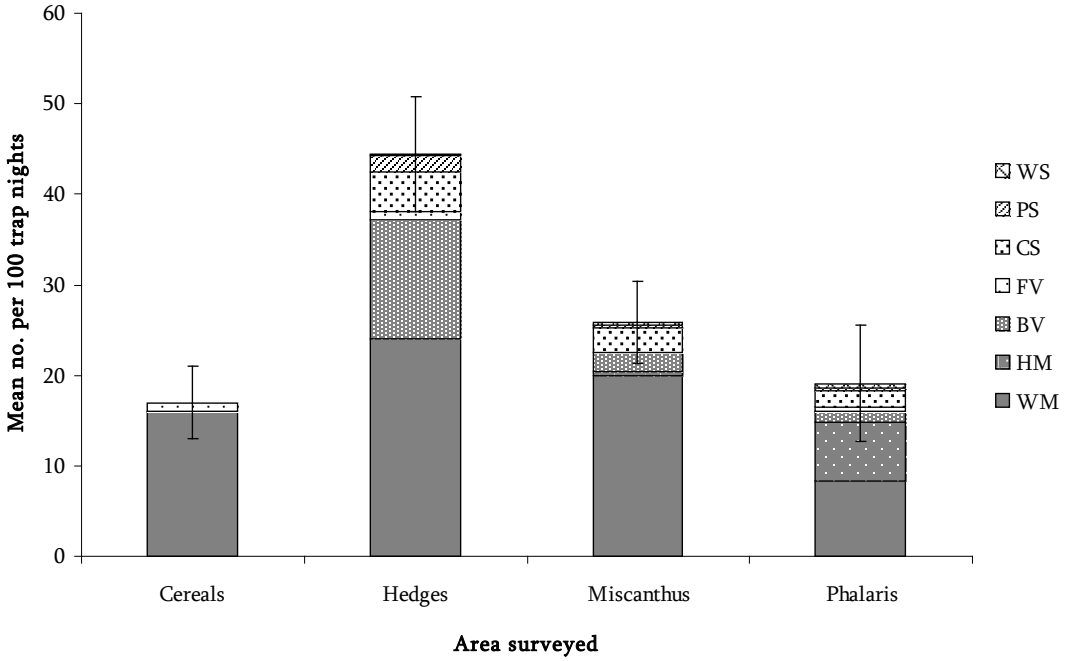

Figure 3.16 Relative abundance of the different small mammal species trapped in each habitat at field site "N" in Year 2. Error bars represent ±1SE for mean no. of all species per 100 TN.

In addition to being the most abundant small mammal trapped overall, the wood mouse was the most widespread species and appeared in a higher percentage of transects in all areas except the comparison plots than any other species. In Year 1 they were found in significantly higher numbers in *Miscanthus* than in *Phalaris*, the headlands or comparison plots (Kruskal-Wallis test: H (3, N= 173) = 32.938, $P < 0.0001$). Year 2, also showed significant differences between areas (Kruskal-Wallis test: H (3, N= 169) = 17.541 $P < 0.001$) with most wood mice in the hedges, then the *Miscanthus*. The only significant differences existed between the hedges and *Phalaris* ($P < 0.001$) and *Miscanthus* and *Phalaris* ($P < 0.05$).

Yellow-necked mice were not found in the comparison plots and were generally caught in low numbers as they only occurred at two sites in the study ('LL' and 'HM'). However, numbers were highest in the headlands, followed by *Miscanthus* and *Phalaris*, although these differences were not significant (Kruskal-Wallis test: H (3, N= 172) = 5.823 $P = 0.121$).

Harvest mice were found more frequently in *Phalaris* than any other area in which they were caught. Although it was not a significant result for the two trapping periods during which they were caught in Year 1, a significant preference for *Phalaris* was revealed in Year 2 (Kruskal-Wallis test: H (3, N= 169) = 37.290 $P<0.0001$).

Field vole numbers showed significant differences in the separate areas sampled in Year 1 (Kruskal-Wallis test: H (3, N= 172) = 10.808 $P = 0.013$), with the highest numbers found in *Phalaris* and comparison plots > *Miscanthus* > headland. However, there was no statistical difference between the *Phalaris* and comparison plots (Mann-Whitney U-test $P = 0.717$). In Year 2, field vole captures appeared to be lower (10 compared with 33 in Year 1) and no significant preference for any area was shown (Kruskal-Wallis test: H (3, N= 169) = 5.620 $P = 0.132$).

No bank voles were caught in the comparison plots. In Year 1, their numbers were similar in the headlands and *Phalaris*, but fewer in *Miscanthus*, but these differences were not significant (Kruskal-Wallis test: H (3, N = 172) = 2.587, $P = 0.460$). In Year 2, significant differences between areas was seen (Kruskal-Wallis test: H (3, N= 169) = 56.4864 $P<0.001$) with a preference for the hedges over any other habitat ($P<0.01$).

Common shrews were most numerous in *Phalaris* then *Miscanthus*, comparison plots and headland, but this variation was not a significant effect in Year 1 (Kruskal-Wallis test: H (3, N= 172) = 4.876 $P = 0.181$). In Year 2 there was a significant difference between areas (Kruskal-Wallis test: H (3, N= 169) = 8.774, $P<0.05$) but when this was tested using multiple comparisons for the different areas, no significant preference was demonstrated.

Pygmy shrews and water shrews were caught in very low numbers in Year 1 (one each in *Phalaris*) and therefore their crop preference was impossible to calculate. However, during Year 2, a larger number were caught. Pygmy shrews showed significant differences in abundance between areas trapped (Kruskal-Wallis test: H (3, N= 169) = 12.532 P <0.01), but as with the common shrew, no habitat preference was demonstrated. Water shrews were caught in all areas other than the comparison plots and did not show any significant preferences (Kruskal-Wallis test: H (3, N= 169) = 3.332 P = 0.343).

The arable comparison plots in Year 2 included the cereals spring barley and maize, which were only surveyed from when the crops were >20 cm high until harvest. This resulted in a short trapping season from early July until late October. Wood mice were found in both the barley and maize (12.5 and 18.3 per 100 TN respectively) and one field vole was found in the barley (equivalent to 2.5 per 100 TN). No other species was found in the cereals and numbers for the same time period were lower in the cereals than the biomass crops although this was not a significant difference (Table 3.10).

3.3.3 Edge effect

No significant differences in total small mammal catch were demonstrated between transects at differing distances from the edge of either of the biomass crops or in the cereal comparison plots (Table 3.12).

Table 3.12 Kruskal Wallis (K-W) test for differences between transects for total mammals per 100 TN in individual crops and years (CP = comparison plots).

Year	Crop	K-W H	N	P
1	*Miscanthus*	1.021	51	0.600
1	*Phalaris*	1.311	57	0.519
2	*Miscanthus*	2.702	58	0.259
2	*Phalaris*	0.509	37	0.775
2	Cereal CP	2.352	10	0.125

3.3.4 Seasonal changes in small mammal assemblage

The total number of small mammals caught in the biomass cropped areas showed a significant seasonal difference between sampling periods in Year 1 (Kruskal-Wallis ANOVA by Ranks; H (5, N= 51) = 33.072 P <0.0001) with numbers rising from their lowest in April to a peak in December and declining again in February. In the non-biomass cropped areas (headlands and comparison plots), maximum numbers were also trapped in December, but no significant difference existed between months (Figure 3.17). Within the biomass crops, no significant seasonal differences in total small mammal catch were seen in Year 2, although actual numbers were at their lowest immediately after harvest in April, and also in January of Year 2 after the harsh winter of 2009-10 (Figure 3.18). In the hedgerows, Kruskal-Wallis tests showed significant seasonal differences (H (9, N = 64) = 22.806, P = 0.007). Multiple comparisons showed this difference to only be significant for small mammal counts in October and May (P = 0.033). Small mammal abundance showed a negative correlation with increasing mean daily temperatures at each survey during Year 1 (r_s = -0.30, P <0.001).

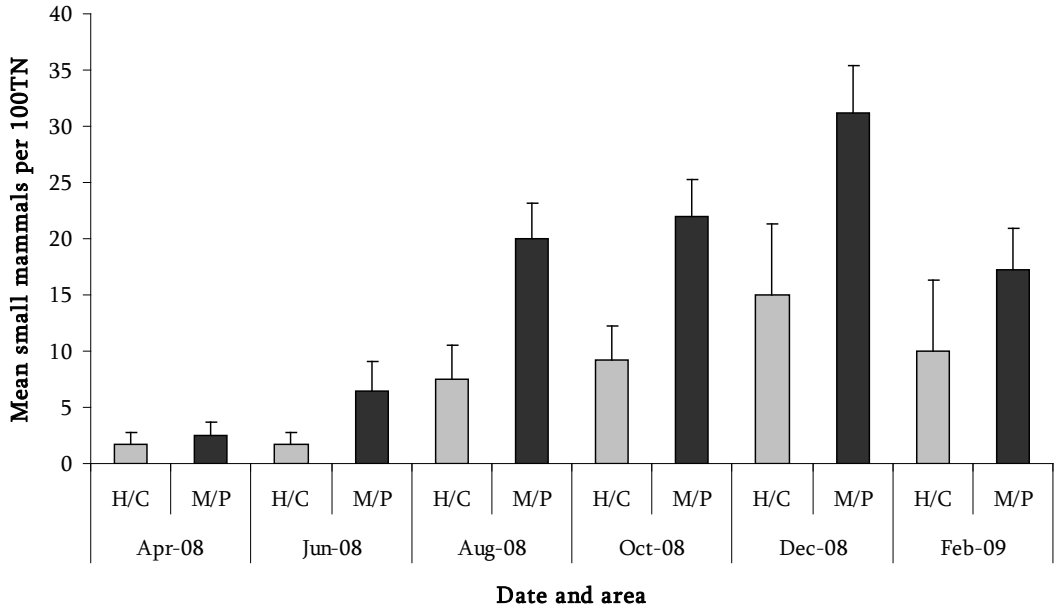

Figure 3.17 Year 1 seasonal variation in total small mammal numbers trapped in biomass cropped areas M/P (*Miscanthus* and *Phalaris*) and non-cropped areas H/C (headlands and comparison plots). Mean per 100 TN ±1SE are shown.

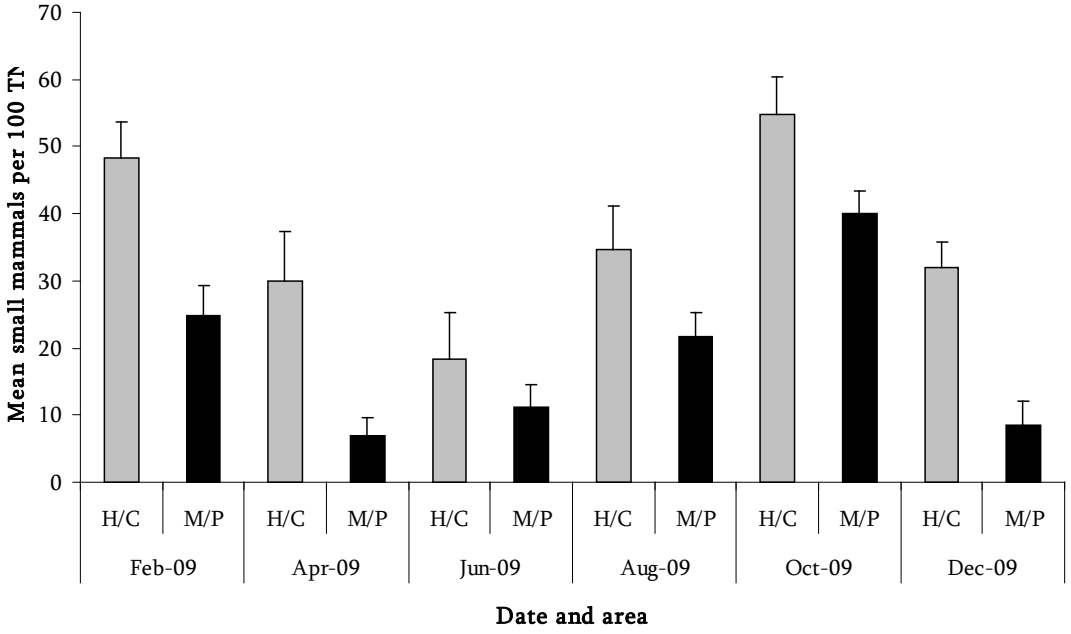

Figure 3.18 Year 2 seasonal variation in total small mammal numbers trapped in biomass cropped areas M/P (*Miscanthus* and *Phalaris*) and in the hedgerows and comparison plots (H/C). Mean count per 100 TN ±1SE are shown.

In the cereal comparison plots, no seasonal difference was recorded (Kruskal-Wallis test H (3, N = 10) = 3.173, $P = 0.366$), but the short duration of trapping due to the crop cycle may have rendered this analysis unreliable.

An analysis of the cumulative number of different species trapped over time in the different crops and at the different field sites was made. The species accumulation curves for individual crops and sites in Figures 3.19 and 3.20 show that in many areas, maximum species diversity was only accounted for after 10 – 12 months of trapping, which for this study coincided with winter months. A further species accumulation curve (Figure 3.21) shows the time taken to trap the maximum number of species at site 'N' in Year 2.

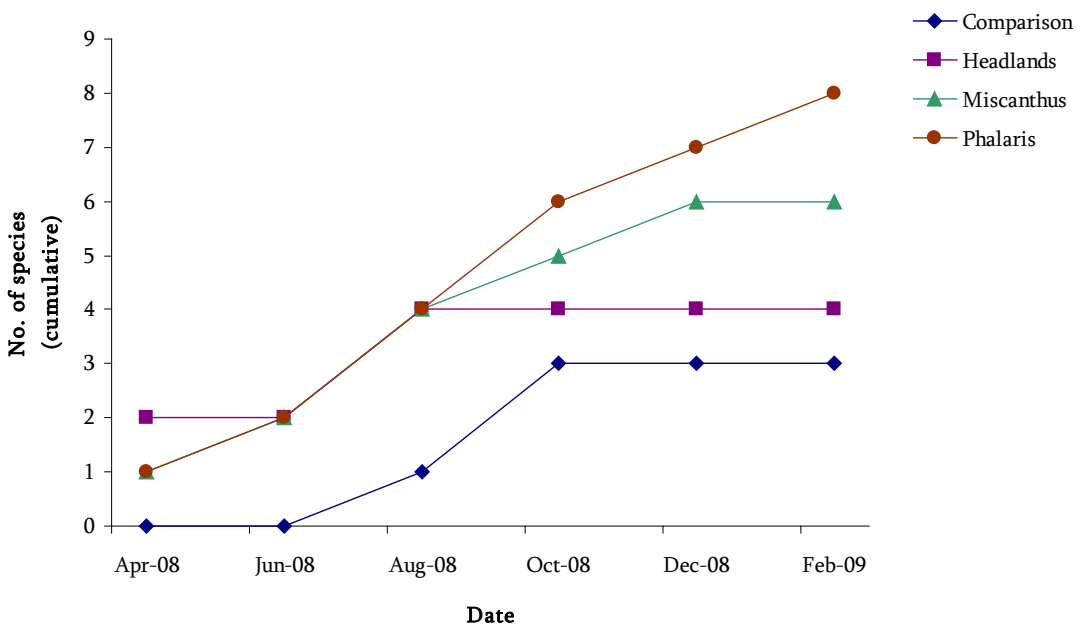

Figure 3.19 Species accumulation curve showing the time taken to trap the maximum number of small mammal species in the different areas surveyed during Year 1, using combined data from the four field sites.

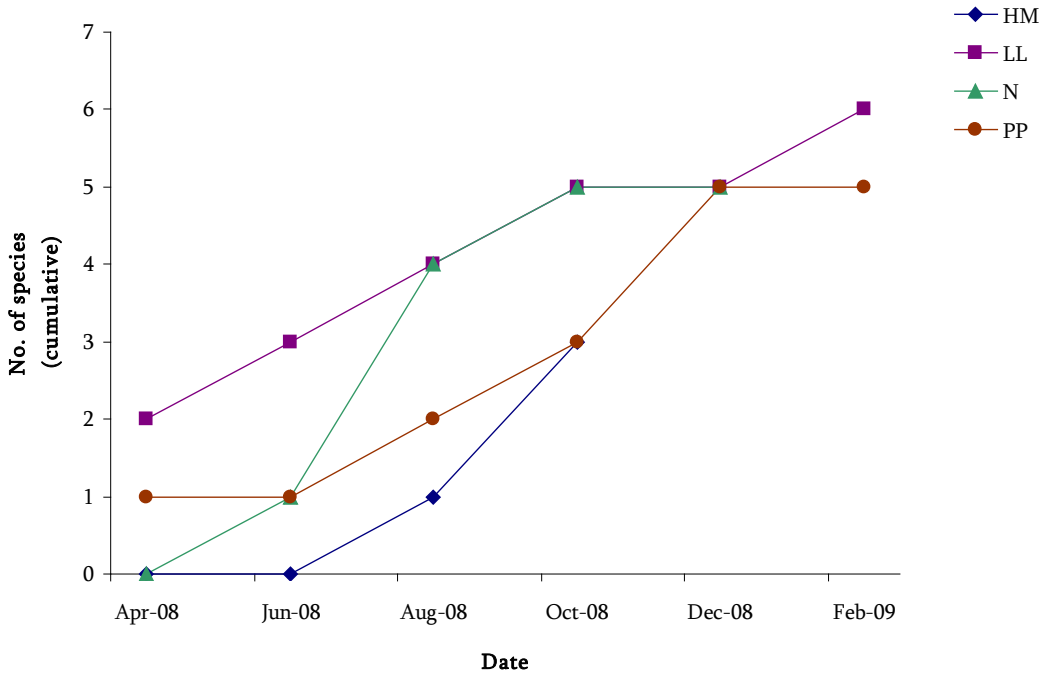

Figure 3.20 Species accumulation curve showing time taken to trap the maximum number of small mammal species in the different field sites during Year 1, using combined data from the different areas surveyed at each site.

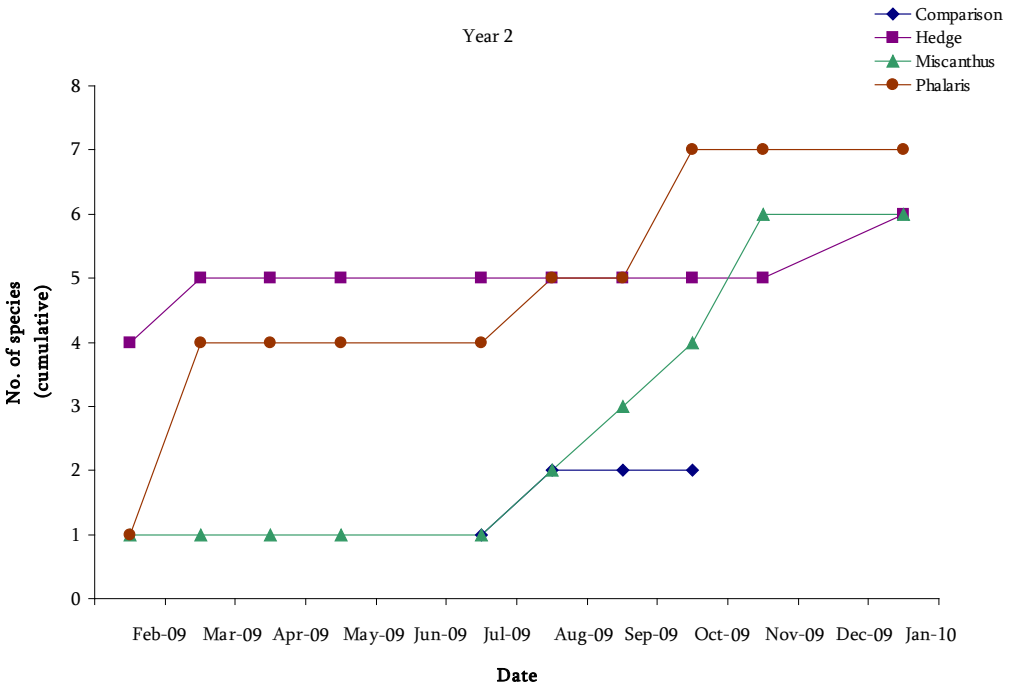

Figure 3.21 Species accumulation curve showing time taken to trap the maximum number of small mammal species in the different areas surveyed during Year 2 using combined data from the four field sites.

3.3.5 (a) Diversity indices

Phalaris contained the most diverse assemblage of small mammals and had the highest number of species in both years (see Table 3.13).

Table 3.13 Counts of small mammals, species number and diversity index scores for the different habitats surveyed. Simpson's Index of Diversity: 1 = maximum diversity and Shannon-Wiener Index: maximum diversity occurs at 1.946.

Year	Survey area	No. species	No. individuals per 100 trap nights	Simpson's Index	Shannon Index
1	**Comparison plots**	**3**	**3.5**	**0.52**	**0.80**
2	Comparison plots	2	17	0.12	0.22
1	**Headlands**	**4**	**8.6**	**0.53**	**0.98**
2	Hedges	6	41.2	0.61	1.20
1	***Miscanthus***	**6**	**18.4**	**0.31**	**0.72**
2	*Miscanthus*	6	25.9	0.39	0.81
1	***Phalaris***	**8**	**11.6**	**0.68**	**1.40**
2	*Phalaris*	8	17	0.69	1.38

Although *Miscanthus* contained the highest overall number of small mammals per trap night in Year 1, it contained fewer species than *Phalaris*. In Year 2, the hedges

contained the highest number of individuals, but the same number of species as *Miscanthus*.

3.3.5 (b) Seasonal diversity changes

Catch (per 100 trap nights) from the different sampling sessions was divided into three seasonal groups of four months each in each habitat. Diversity indices were calculated for each group, with zero diversity value given for any habitat/group with only one species present. Year 1 and Year 2 diversity values were plotted together for the biomass grasses, but were plotted separately for the hedge and headlands, as these were not considered to be equivalent habitat in terms of their small mammal population distribution (Figures 3.22 – 3.25). Diversity values in the biomass grasses changed over time, but not in a manner that was consistent between the two years. In both *Miscanthus* and *Phalaris*, the lowest diversity scores were recorded in the period April-July of Year 2. A more consistent pattern was shown in the headlands and hedgerows, with very little variation in Simpson's Index at the different times of year.

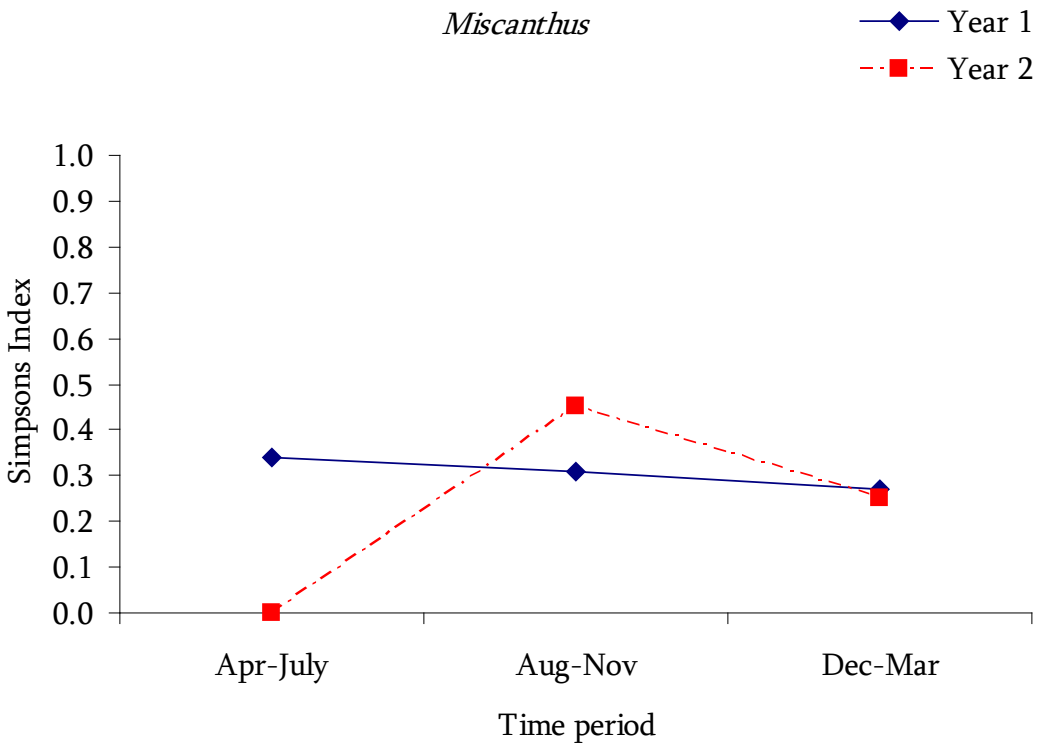

Figure 3.22 Simpson's Index for small mammals in *Miscanthus*, showing seasonal values for Years 1 & 2.

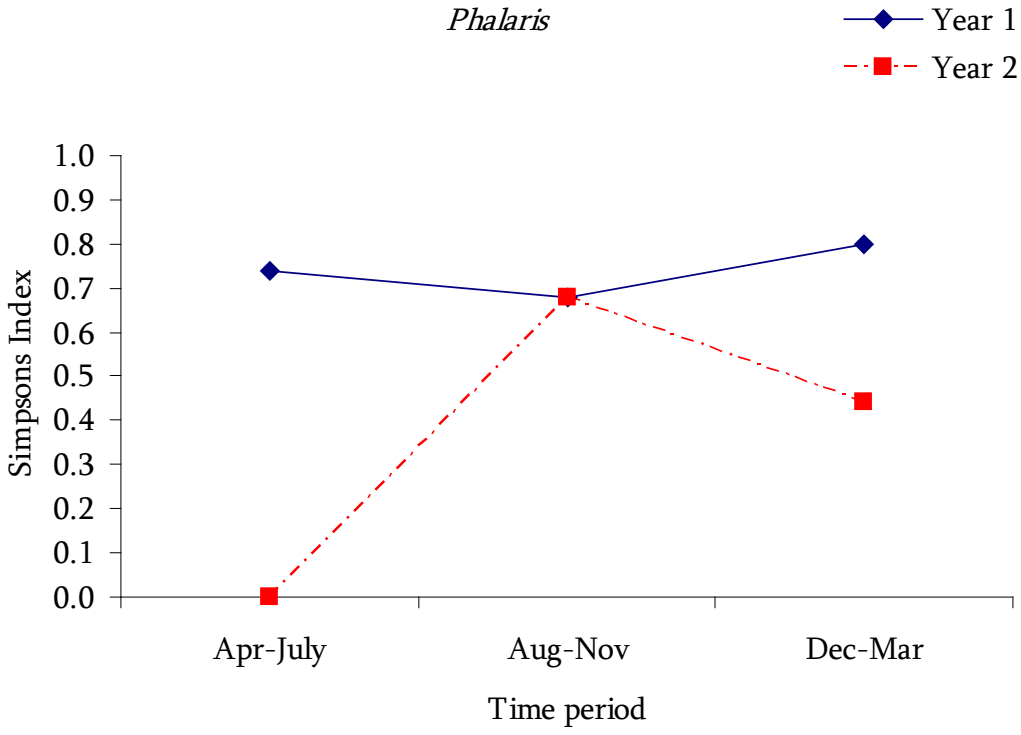

Figure 3.23 Simpson's Index for small mammals in *Phalaris*, showing seasonal values for Years 1 & 2.

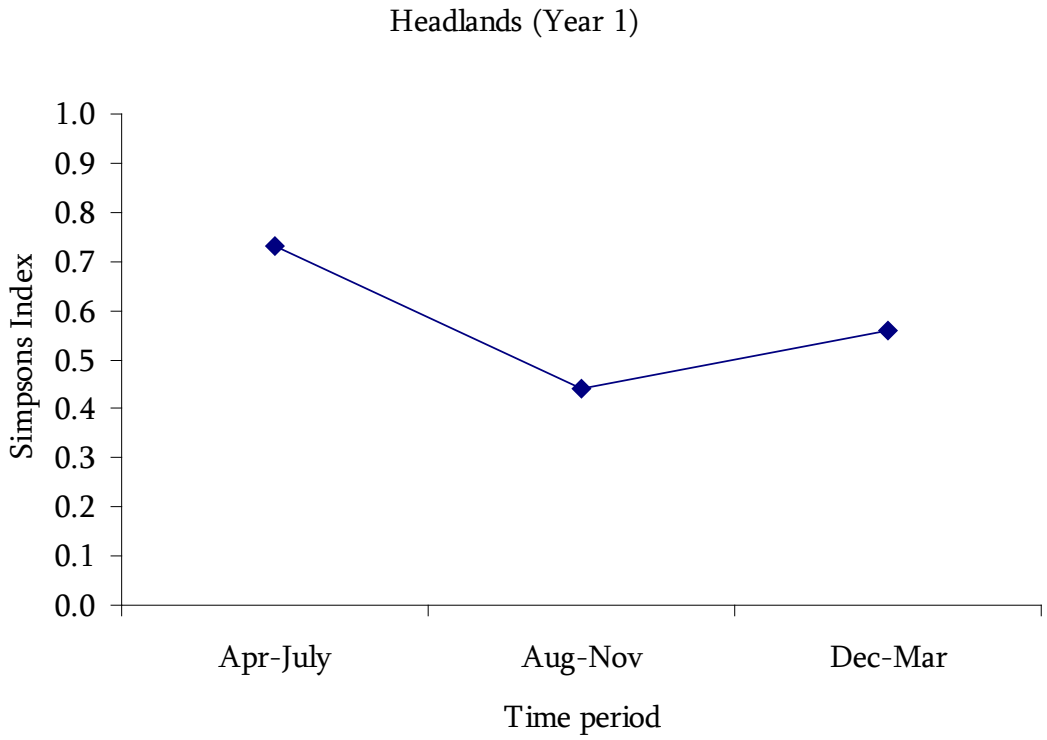

Figure 3.24 Simpson's Index for small mammals in the headlands, showing seasonal values for Year 1.

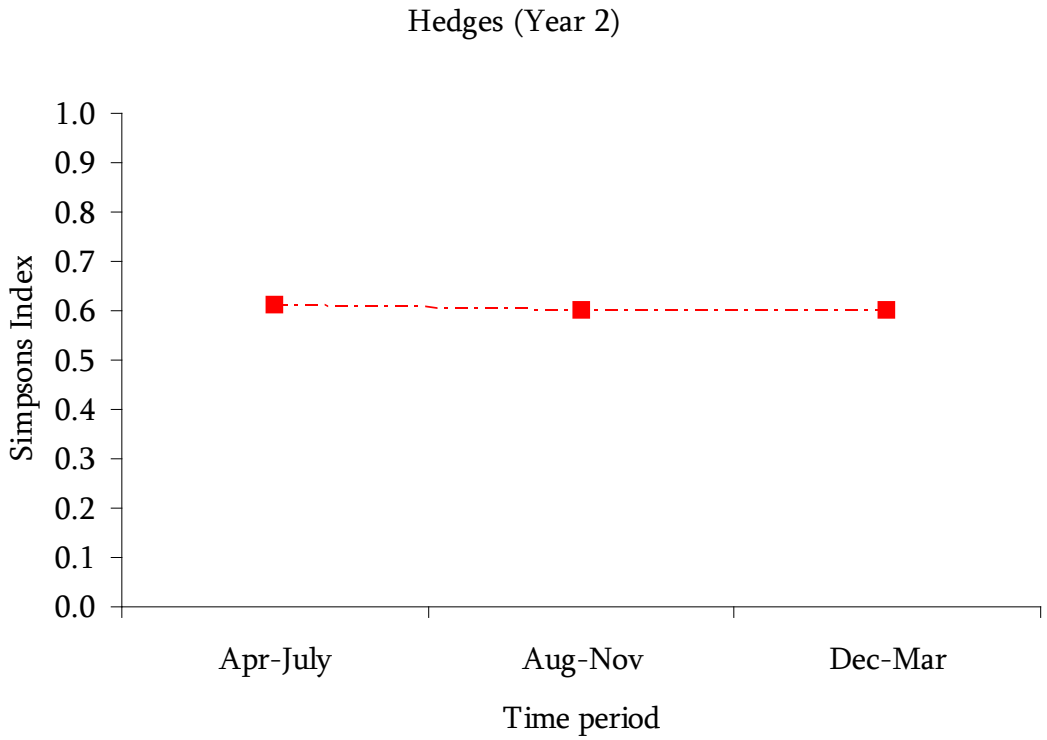

Figure 3.25 Simpson's Index for small mammals in the hedges showing seasonal values for Year 2.

3.3.6 Crop management effects

The two *Phalaris* fields at 'PP' were mown at different times: 'PP1' in spring and 'PP2' in late summer (Year 1). The total number of all mammal species caught in these two fields closely followed the timing of mowing, with an immediate reduction seen when only stubble was present. The highest numbers of small mammals were caught in December in 'PP1'. Factorial ANOVA of total mammal numbers at all dates and both fields showed significant differences between 'PP1' and 'PP2' *Phalaris* crops ($F_{(1, 18)} = 4.418$, $P = 0.049$) and also sampling dates ($F_{(5, 18)} = 4.680$, $P = 0.007$) but the strongest effect was seen for combined date and site ($F_{(5, 18)} = 9.8291$, $P = 0.0001$). Figure 3.26 shows these differences plotted by sampling date, with the date of mowing also indicated.

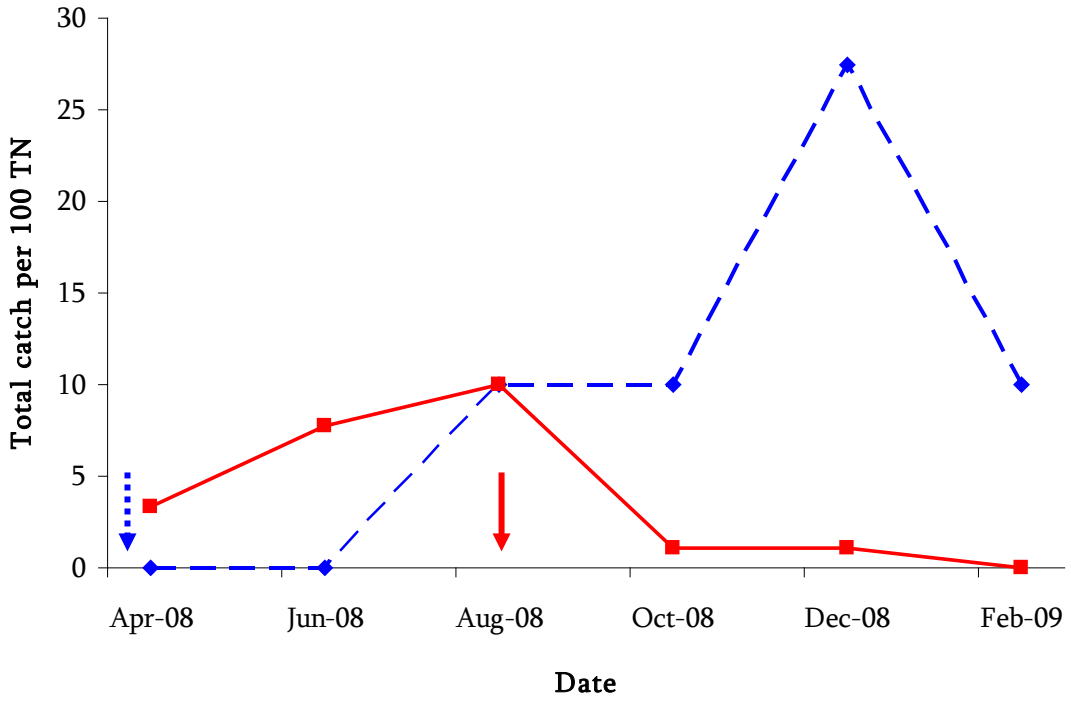

Figure 3.26 Total mammal catch (per 10-trap transect) by month in 'PP' *Phalaris* in relation to mowing dates.
Key: 'PP1' 'PP2' Mowing date of 'PP1' Mowing date of 'PP2'.

The association between total mammal catch in 'PP' *Phalaris* and the crop height is further illustrated in Figure 3.27.

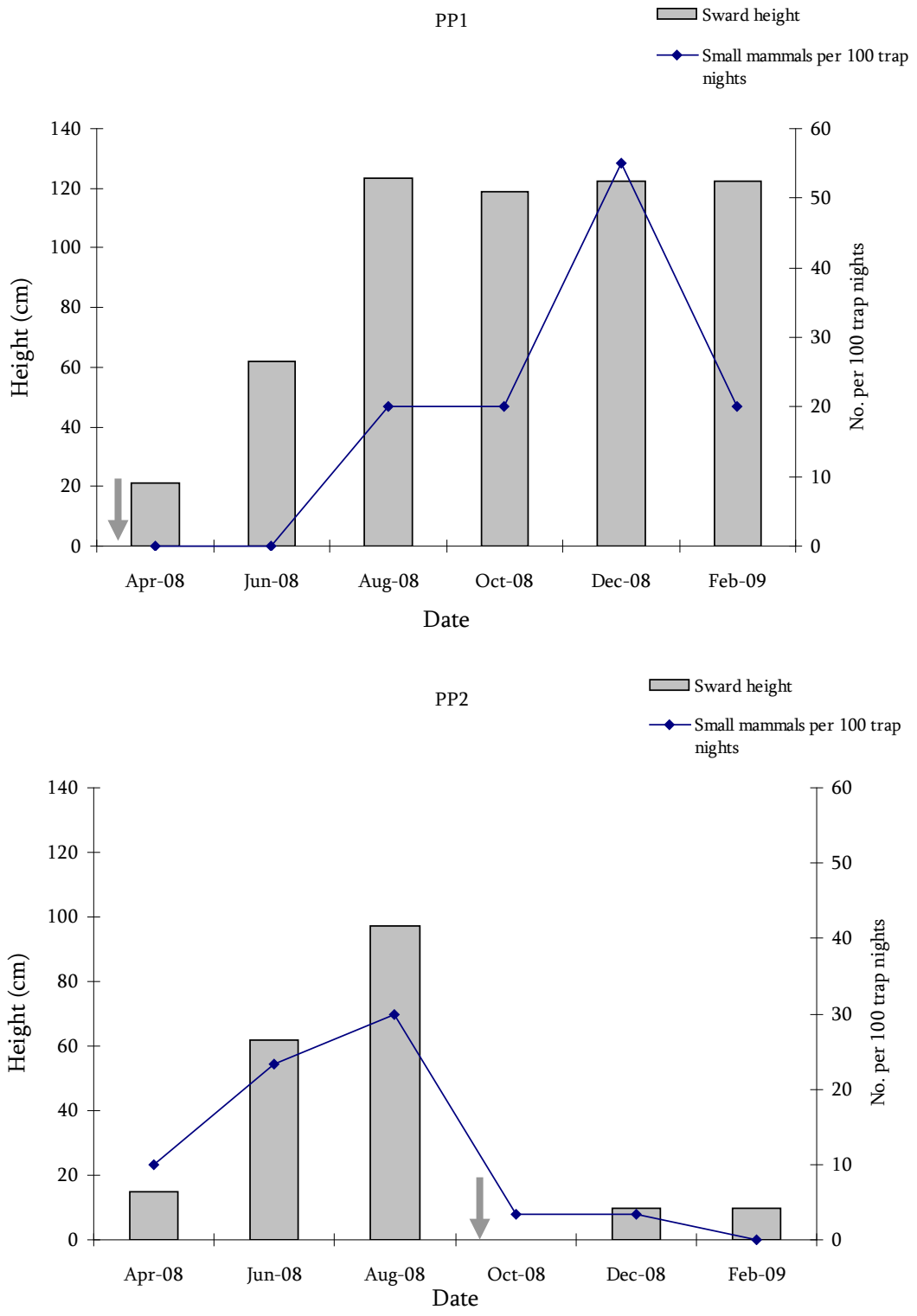

Figure 3.27 The relationship between total mammals caught in 'PP' *Phalaris* and height of the crop through the trapping season in 'PP1' and 'PP2'. Mowing dates are indicated by ↓.

3.3.7 Crop characteristics

As in the *Phalaris* at site 'PP', the total number of small mammals at all the sites in Year 1 was correlated with sward height in both *Miscanthus* and *Phalaris*, but not in the headlands. *Miscanthus* showed the strongest positive correlation (Spearman ranked correlation r_s = 0.765, P < 0.05, N = 51 trap lines surveyed), but *Phalaris* height also correlated positively with total mammal catch (Spearman ranked correlation r_s = 0.657, N = 57, P < 0.05) as shown in Figures 3.28 (a) and (b).

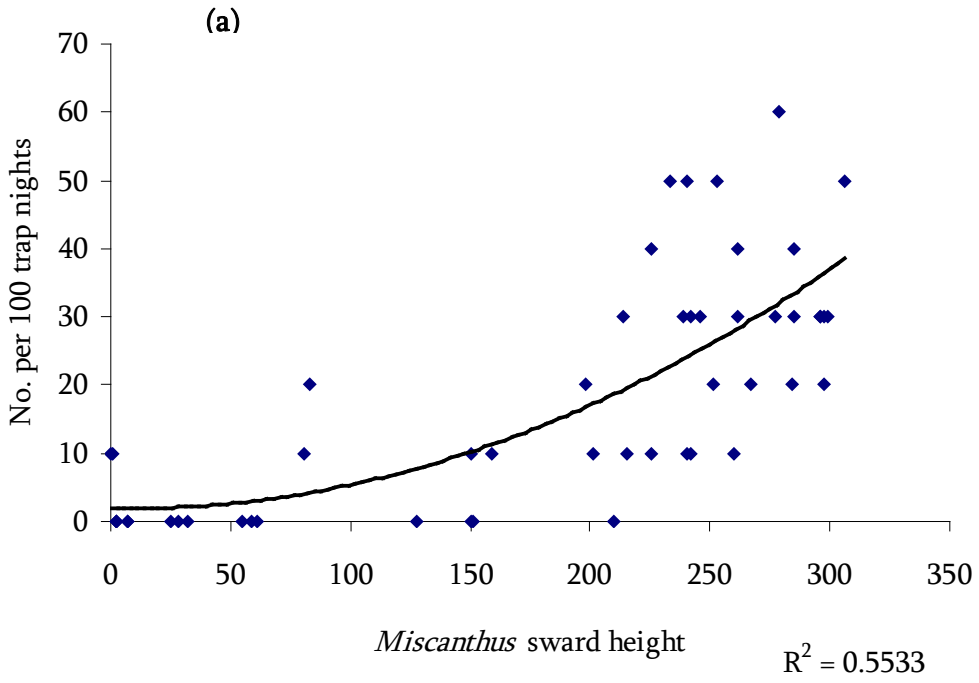

Figure 3.28(a) Correlations between crop sward height (cm) and total mammal catch in *Miscanthus* with polynomial trendline fitted.

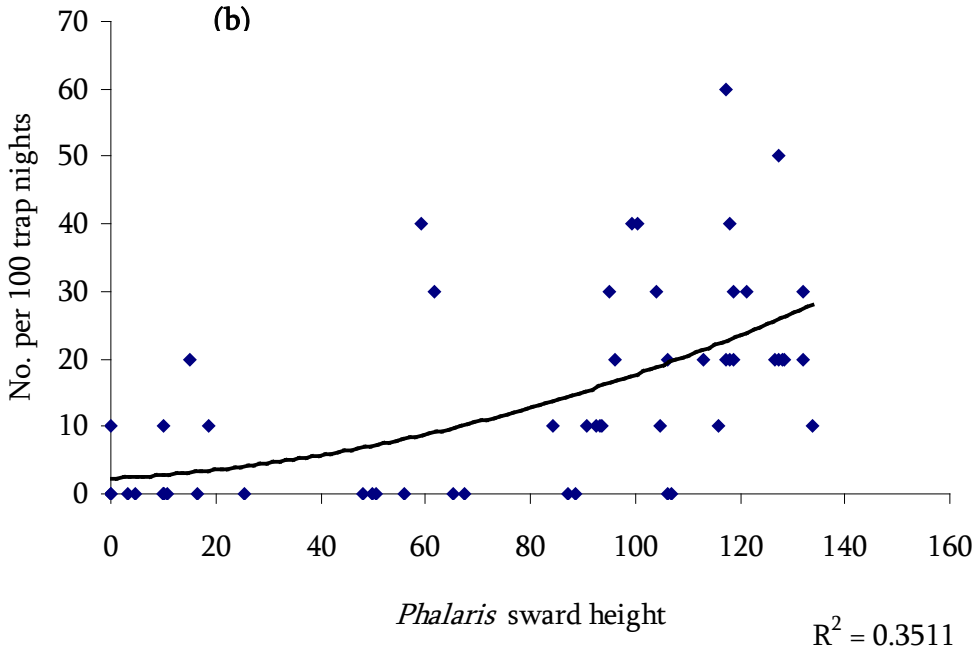

Figure 3.28(b) Correlations between crop sward height (cm) and total mammal catch in *Phalaris* with polynomial trendline fitted.

Wood mouse abundance was positively associated with crop height in both *Phalaris* and *Miscanthus* (Spearman ranked correlation r_s = 0.22, P <0.05, N = 57 and r_s = 0.71, P <0.05, N = 51 respectively). Field voles also showed a positive relationship with sward height in *Phalaris* (r_s = 0.39, P <0.05, N = 57). When other factors relating to the crop, such as percentage cover and total weed cover were taken into account (combined Year 1 and Year 2 data, CCA), the wood mouse, common shrew and pygmy shrew all showed an association with crop height (Figure 3.29).

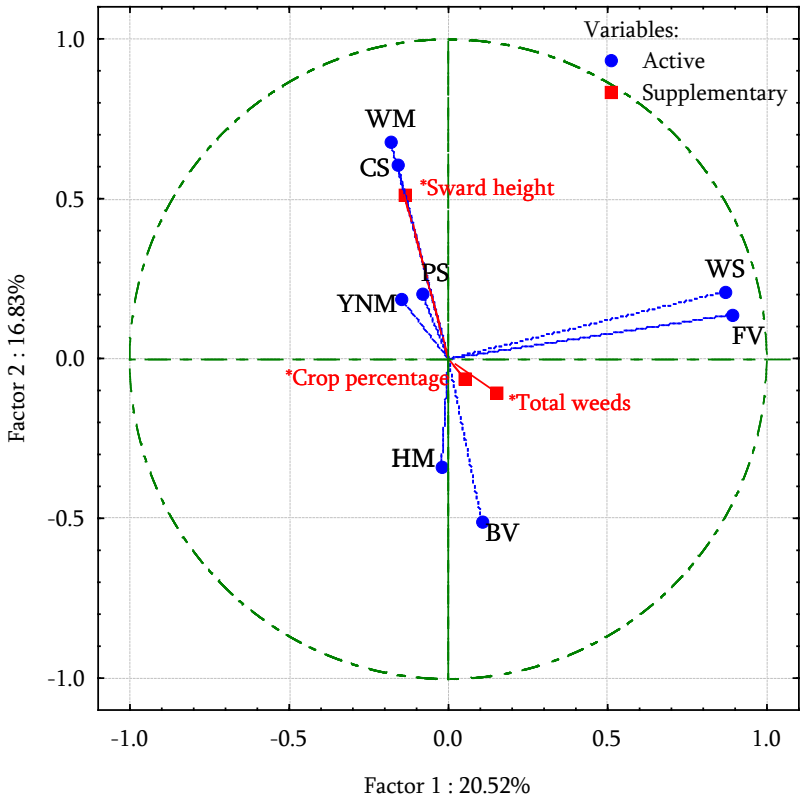

Figure 3.29 CCA plot of small mammal species abundance in relation to percentage cover of biomass crop, crop height and the percentage cover of weeds present (combined Year 1 and Year 2 data).

Total abundance of small mammals and some individual species abundances were positively correlated with crop percentage cover (Year 1; Table 3.14).

Table 3.14 Correlation matrix for small mammals and crop percentage cover in Year 1. Significant Spearman R-values are highlighted: * $P<0.05$ ** $P<0.01$, NS = not significant.

	Spearman R-value / significance			
Type	*Miscanthus*		*Phalaris*	
Total mammals	0.34	*	0.33	*
Harvest mouse	0.17	NS	0.45	**
Field vole	0.32	*	-0.05	NS
Wood mouse	0.31	*	0.11	NS

Wood mice, which showed positive correlations with both *Miscanthus* sward height and percentage cover showed a significant negative correlation with light intensity reaching ground level (r_s = -0.56, $P<0.001$, N = 51).

Field voles demonstrated a positive relationship with percentage cover of non- crop grasses (Gramineae) in the *Phalaris* crops (r_s = 0.50, P < 0.001, N = 57). Harvest mice demonstrated a negative correlation with weed cover in *Phalaris* (r_s = -0.29, P < 0.05, N = 57) whereas common shrews had a positive association with weed cover in *Miscanthus* (r_s = 0.33, P < 0.05, N = 51).

3.3.8 Interspecific associations

A CCA plot of small mammal species in both crops showed some grouping effects. Three groups were seen along different axes: one group comprising wood mice, common shrews, pygmy shrews and yellow-necked mice. Opposite this axis were bank voles and harvest mice, with a separate grouping existing for water shrews and field voles (Figure 3.30).

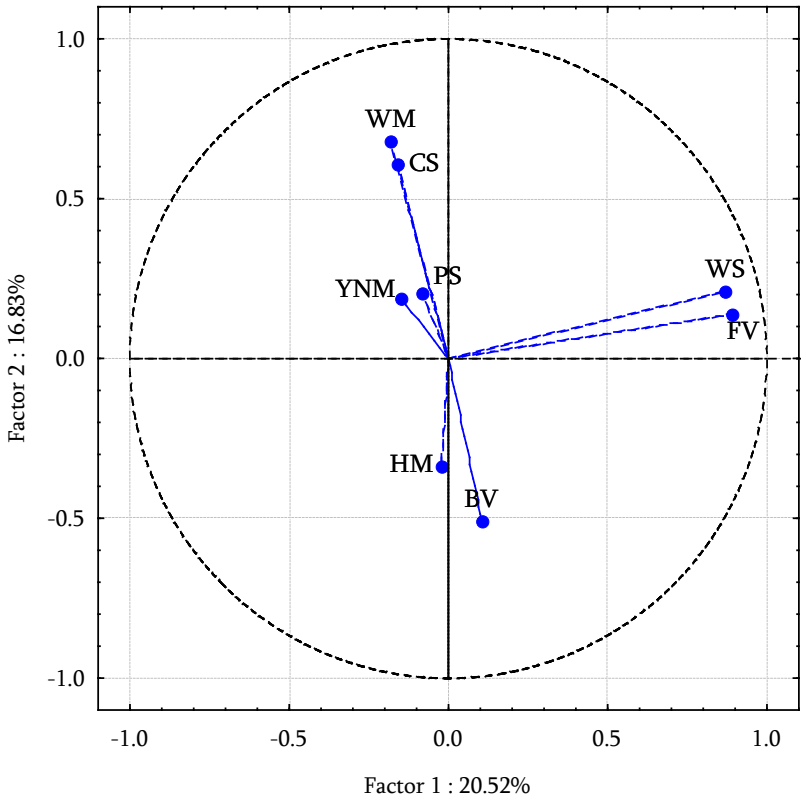

Figure 3.30 CCA plot of associations between small mammals in biomass crops (*Miscanthus* and *Phalaris* combined).

3.3.9 Feeding ecology

Distribution of small mammals in and around the crops was partially influenced by their diet. Small mammal species with an omnivorous diet comprised the highest proportion of individuals in all areas except the grass comparison plots, where herbivores dominated. A small proportion of insectivores were present in all areas except the barley and maize (Figure 3.31).

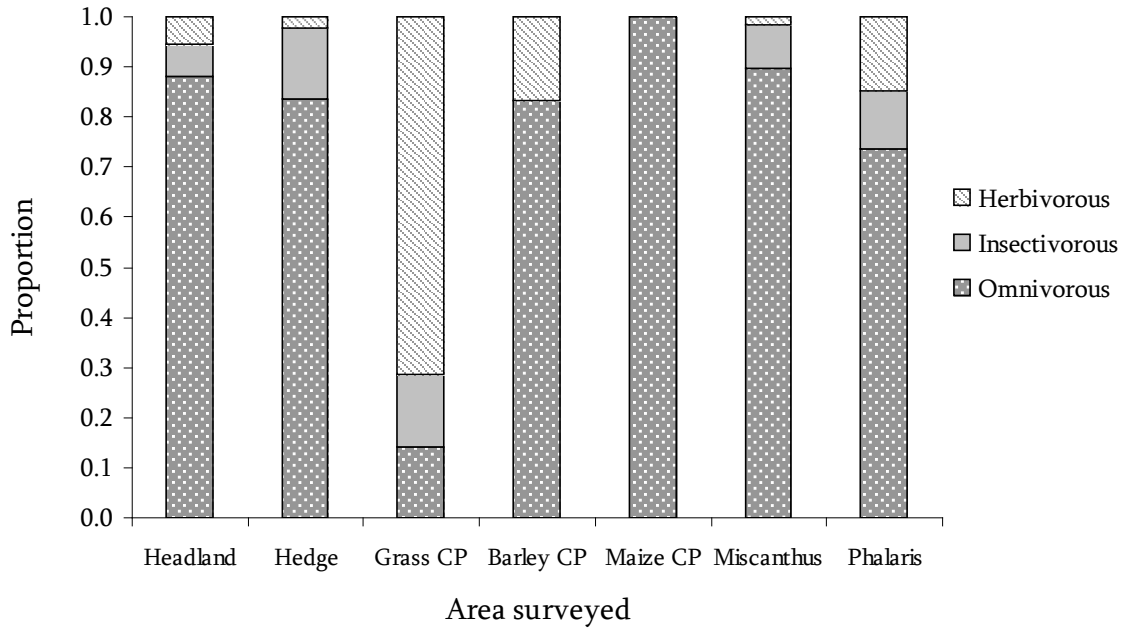

Figure 3.31 Proportions of small mammals within the different areas surveyed in both Year 1 and 2, grouped according to diet. (CP = comparison plot).

When data for Year 1 and Year 2 were combined, the omnivore group (comprising wood mice, yellow-necked mice, harvest mice and bank voles) showed significant differences in their distribution throughout the areas surveyed (Kruskal-Wallis test: H (6, N = 361) = 79.203 $P < 0.0001$), with highest numbers in the hedges and the lowest numbers in the grass comparison plots (Table 3.15 and Figure 3.32).

Table 3.15 Pairwise comparison *P*-values (adjusted for multiple comparisons within an overall Kruskal-Wallis test) for significant differences between the areas surveyed for the numbers of omnivorous small mammals per 100 TN. CP = comparison plots.

	Grass Comparison	Headland	*Miscanthus*	*Phalaris*	Barley Comparison	Maize Comparison
Grass CP						
Headland	0.035					
Miscanthus	<0.001	0.245				
Phalaris	0.025	1.000	0.027			
Barley CP	1.000	1.000	1.000	1.000		
Maize CP	0.091	1.000	1.000	1.000	1.000	
Hedge	<0.001	<0.001	0.002	<0.001	1.000	1.000

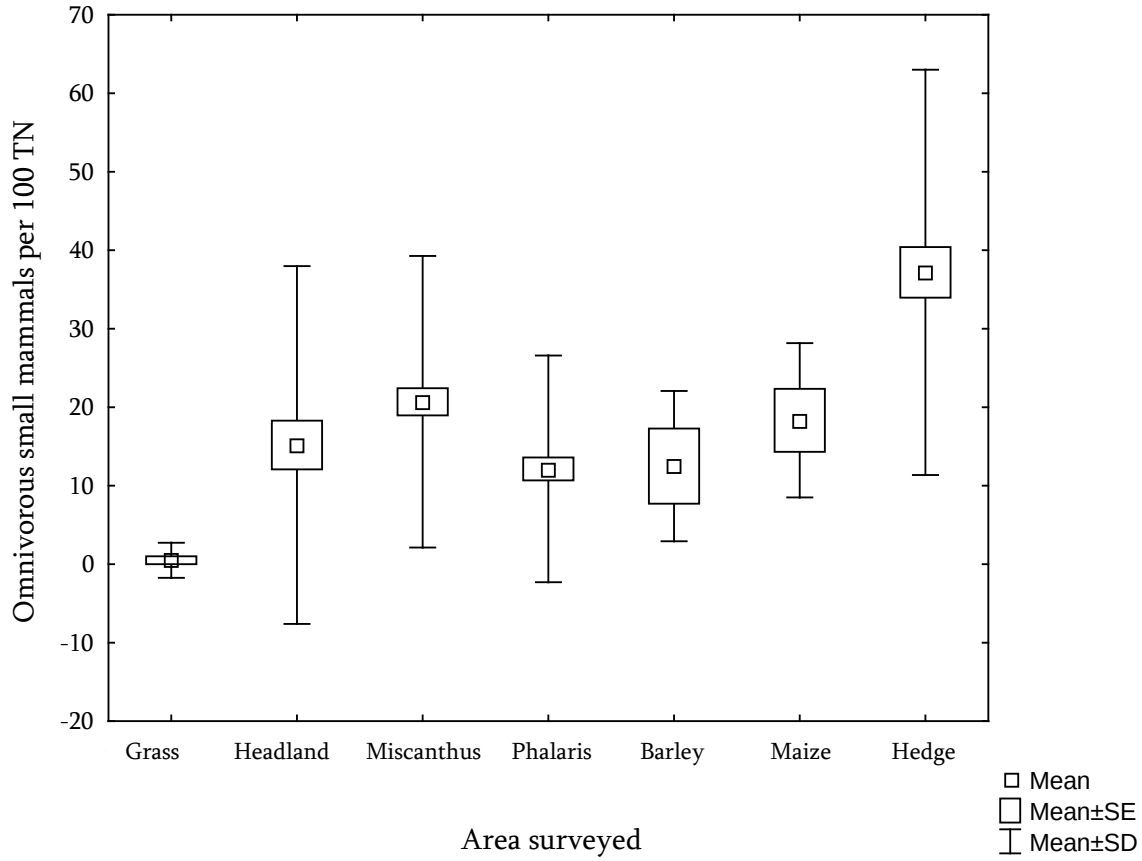

Figure 3.32 Distribution of omnivorous small mammals in the different areas surveyed in Year 1 and 2. Figures shown are means per 100 TN with SE and SD also shown.

The insectivore group (all three species of shrew) also showed significant differences in distribution (Kruskal-Wallis ANOVA by ranks: H (6, N = 361) = 32.593, $P < 0.0001$) with higher numbers in the hedges, but multiple comparisons failed to identify significant differences between the areas surveyed. No significant results were demonstrated for the herbivores (represented by the field vole).

3.3.10 Mortalities

From a total of 1,810 captures over the two years of trapping, 13 animals were found dead in traps, equating to an overall mortality rate of 0.7%. A breakdown of deaths per species is shown in Table 3.16. Quantities of live food placed in the trap were increased each time a shrew death occurred and apart from a common shrew death in October 2009 where live food remained in the trap, no deaths occurred after September 2009. Another common shrew death in March 2009 was likely to have resulted from the fact that a wood mouse was also caught in the trap at the same time. The only dead harvest mouse was the first one to be trapped in Year 1 and was a juvenile. Adequate food supplies and hay remained in the trap, so the cause of this death was unknown.

Table 3.16 Small mammal mortality rates for Year 1 and 2 by species.

Species	Animals trapped			Mortalities			
	Year 1	Year 2	Total	Year 1	Year 2	Total	Percentage
WM	143	801	944	0	1	1	0.1%
YNM	12	0	12	0	0	0	0%
HM	8	78	86	1	0	1	1.3%
All mice	**163**	**879**	**1042**	**1**	**1**	**2**	**0.2%**
BV	9	400	409	0	0	0	0%
FV	33	38	71	0	0	0	0%
All voles	**42**	**438**	**480**	**0**	**0**	**0**	**0%**
CS	12	199	211	2	8	10	4.7%
PS	1	35	36	0	1	1	2.8%
WS	1	32	33	0	0	0	0%
All shrews	**14**	**266**	**280**	**2**	**9**	**11**	**3.9%**

3.3.11 Multiple mammal captures, and non-mammal captures

Multiple captures within the same trap occurred far more frequently than had been expected and comprised different combinations of animals (Table 3.17). Apart from the common shrew / wood mouse combination mentioned above, neither party of any other combination seemed to suffer as a consequence.

Wrens *Troglodytes troglodytes* were caught in Longworth traps on five occasions (including a bird previously ringed in a mist-net capture), and a juvenile common toad *Bufo bufo* was recorded once.

Table 3.17 Frequency of the types of multiple occupancy in the same Longworth trap for all small mammal captures in Year 1 and 2.

Combination	Times recorded
Wood mouse + wood mouse	5
Bank vole + bank vole	3
Harvest mouse + harvest mouse	1
Wood mouse + bank vole	2
Wood mouse + common shrew	1
Common shrew + pygmy shrew	1

3.4 Discussion

Live trapping for small mammals in both the Year 1 surveys across four field sites and Year 2 surveys at one site revealed that the biomass crops were well utilised by up to eight small mammal species. Although in Year 2, the hedges contained the highest abundance of small mammals, the diversity of the assemblage was equivalent to that found within *Miscanthus*, but was less diverse than the assemblage in *Phalaris*. Population numbers peaked in winter, at a time when the spring-mown biomass was still standing and providing good habitat not provided by other agricultural crops.

3.4.1 Trapping techniques

In the first year of the study, the trip weight of the treadles in the traps was set at medium sensitivity and resulted in low catch of pygmy and common shrews. The subsequent intensive survey of harvest mice at one of the field sites (see Chapter 4) was performed after reducing trip weight and many more pygmy and common shrews were trapped during this time, suggesting that increasing the trip weight threshold does indeed prevent shrew capture if they are not the target animal in a study.

Time and funding dictated that Longworth traps were only set for one night on each survey of each site in Year 1, which may have influenced and reduced total catch. Field voles have been reported to show "new object reaction" (neophobia), which reduces their likelihood of entering traps on their first encounter with them (Chitty & Kempson 1949). Sealander *et al.* (1958) found that only 50% of approaches by house mice to Sherman traps resulted in captures. Pre-baiting is a technique whereby baited traps are set for one or more nights with their doors locked open, allowing the animals to enter the traps and feed without being caught, thus becoming accustomed to them. This technique in combination with trapping

for several consecutive nights, is recommended where possible (Gurnell & Flowerdew 2006).

Tombs (unpublished) trapped monthly for 4 consecutive nights in 2007 in both *Miscanthus* and *Phalaris*. Her data from 1,800 trap nights showed that 38% (N = 61 out of 159) of the final catch of wood mice, 29% (N = 28 out of 97) of yellow-necked mice, 25% (N = 1 out of 4) of bank voles and 29% (N = 15 out of 54) field voles were caught during the first night of trapping. The only four common shrews were caught on the second night of trapping.

Similar analysis was performed by Underhill (2003) on the captures of three species at two sites in June. She found a similar mean rate of trap success for wood mice on the first night (44%), but caught fewer field voles and more common shrews: these two species showed a particularly reduced tendency to enter traps at an early stage. These rates were much improved after initiating pre-baiting in subsequent months (Underhill 2003).

From these data, it is apparent that one night of trapping will not give a true estimate of population size, but at the very least gives a measure of abundance and was a replicable measure at the different sites.

There may also be some variability in trapping success at different times of year. Tanton (1965) suggests that a reduction in wood mouse captures during the summer months could be due to a changed behavioural response related to higher food availability and the reduced need to explore and therefore enter traps. He therefore also urges caution in using summer data to estimate population size. Similar changes in behaviour resulting in reduced "trappability" over the summer have also been reported in harvest mice, although the reasons for this are not known (Roger Trout, personal communication).

A further factor to be considered when using live traps is the possibility of restricting an animal's range of movement. In a comparison between monitoring small mammal movements using live-trapping and radio-tracking, live traps reduced the apparent distances travelled by small mammals and therefore may not necessarily show their true patterns of movement around a habitat (Szacki 1999).

In this study, the decision to use trap-lines was driven both by the difficulty of gaining access into the full-grown crops and also the intention to show effects of distance from the crop edge. Use of trap lines is considered a valid technique where only a relative index of abundance is required, however results may be ambiguous if the home range of trapped individuals varies in size between habitats (Tanton 1965). In studies where population size estimates are required, a grid pattern and the use of capture-mark-recapture is recommended (Gurnell & Flowerdew 2006). A variation on this is the web design for trap layout, which allows plot-less or distance sampling data analysis (Anderson *et al.* 1983). As Year 1 logistics did not allow for more than one night of trapping at each survey period, no capture-mark-recapture studies were possible.

The Year 2 data considered in this chapter are included in an attempt to expand the depth of understanding of how the small mammal species use the biomass habitat. It is important, however to bear in mind that the results are therefore specific to one site only and may not have the same strength as capture data from multiple sites.

3.4.2 Abundance of individual small mammal species and crop preference

Wood mice were the most abundant small mammal species in all areas except the comparison plots and this reflects findings by Semere & Slater (2007a) in young *Phalaris* and *Miscanthus* crops. Similar results were also found in that more field voles were caught in *Phalaris* than *Miscanthus* (Semere & Slater 2005). However,

this study recorded significantly higher numbers of mammals trapped within the crop fields in Year 1 (mean of 16.8 ±1.59 per 100 TN for both *Phalaris* and *Miscanthus*) compared to the field margins (8.6 ± 1.97 per 100 TN), which is the opposite of Semere & Slater's (2005) findings of 7.9 per 100 TN for the crops and 12.8 for the margins. There was a different distribution again in Year 2, with hedges accounting for a mean of 43.1 ±3.21 per 100 TN and the crops 22.5 ±2.0 per 100 TN. These differences may be due to a number of factors:

1. Differences in field margin structure between Year 1 and Semere & Slater's sites,
2. The headlands in Year 1 acting as a completely different habitat type to the hedges in Year 2,
3. Other site-specific factors. Year 1 data has the advantage of being spread across multiple sites across Wales, whereas Year 2 focuses on a single site and Semere & Slater on a single geographical area.

In terms of individual crops, *Miscanthus* contained a significantly higher mean number of small mammals than *Phalaris* (18.4 ±2.4 per 100 TN and 14.1 ±2.0 per 100 TN respectively in Year 1 and 25.7 ±2.8 per 100 TN and 19.5 ±2.8 per 100 TN in Year 2) and this may have been a function of the greater sward height in the *Miscanthus*.

Yellow-necked mice were caught in small numbers at two sites and in every area except the comparison plots. They are known to be a woodland species, preferring high levels of canopy cover (Marsh & Harris 2000) or undisturbed hedgerows (Kotzageorgis & Mason 1997) where their diet is comprised of tree seeds rather than herbaceous weed seeds (Marsh & Montgomery 2008). So their presence in *Miscanthus*, particularly at site 'LL' which was adjacent to broad-leaved woodland is a little surprising. Whether they were foraging when caught, or simply using the available cover is unknown and only a technique such as radio-telemetry could provide answers as to how they use the crop.

3.4.3 Small mammal species diversity

In Year 1, *Phalaris* contained both the highest number of species (eight) and the highest diversity when species evenness was taken into account. *Miscanthus* contained six species, but had the lowest diversity of all areas sampled. When Year 2 results were added to Year 1, a total of eight species had been trapped in both *Miscanthus* and *Phalaris* in comparison with seven species in the headlands and hedgerows. Again, this differed from the findings of Semere & Slater (2005) who found up to five species in *Phalaris* and only one species (wood mouse) in *Miscanthus*. Throughout both years, *Phalaris* remained the most diverse habitat despite there being seasonal variation in the Simpson's Index scores. In Year 2 at site 'N', a substantial drop in diversity was seen in the biomass crops from April – June. This was likely to be as a result of the material being harvested as no such variation was seen in the hedges during the same time-period. Perennial biomass grass crops are unique in terms of their architecture and management and as such there is little to compare them with in terms of 'natural' habitats. In terms of structure, a *Phragmites* spp. reedbed would be the closest approximation and these have been reported widely as being suitable habitat for harvest mice (Riordan *et al.* 2007; Surmacki *et al.* 2005; Harris 1979), but are also associated with a range of other small mammal species (Scott *et al.* 2008). The results from this study show that biomass grass crops are utilised by the whole range of native small mammals, even those not particularly associated with traditional arable crops.

3.4.4 Edge effect

Small mammals were captured in all the areas of the crops in which traps were set and there was no demonstrable edge effect for any of the small mammal species. Tattersall *et al.* (2002) reported a preference by bank voles for linear habitat such as field margins, but this was not supported by the results of the present study, which recorded bank voles at up to 20 m into the non-linear crops. Harvest mice were also trapped at all transects in the crop regardless of distance from the edge and

again, this disagrees with results reported for arable land by Moore *et al.* (2003). This suggests that the architecture of both *Miscanthus* and *Phalaris* crop fields provides sufficient cover and resources to readily support small mammal numbers that would otherwise be associated with hedgerows or field margins.

3.4.5 Feeding ecology

The small mammals in this study were grouped into three feeding guilds: omnivorous (wood mice, yellow-necked mice, harvest mice and bank voles), insectivorous (all three species of shrew) and herbivorous (field vole). The omnivorous group dominated in all areas except the grass comparison plots, but showed a statistical preference for the hedgerows. This could be due to the additional food resources available there, in terms of fruits, nuts and berries, as well as a different array of seeds and animal matter. As expected, the grass comparison plots had a higher proportion of herbivorous small mammals relative to any other crop or margin habitat, although no statistical preference was shown by them in any one habitat. The weed and invertebrate content of the biomass crops may also be of significance with regard to distribution of small mammals and these factors have been discussed in Chapters 2 & 6.

3.4.6 Crop height and management

Crop height was a significant factor in determining small mammal presence, with total numbers positively correlated with height in both crops in Year 1. When analysed by individual species, the field vole showed a positive association with sward height in *Phalaris* and the wood mouse in *Miscanthus*. No such association was seen for the bank vole or shrews and this may indicate that close ground cover is more important to them than sward height (Churchfield & Searle 2008; Kotzageorgis & Mason 1997). Headlands were unmanaged at all but one site where they were mown annually in September (PP). Despite this, sward height in the headlands had very little influence on small mammal presence. This was

unexpected in view of the findings of Askew *et al.* (2007) and Shore *et al.* (2005), where grassy margins in conventional arable crop fields resulted in higher numbers and diversity of small mammals. These results may be due to higher numbers of small mammals utilising the biomass crop habitat, and the headland therefore being of lesser importance. The only comparison plots where small mammals were found were ungrazed areas of grassland, where tussocks and a litter layer had formed, which is known to be of more importance to field voles than successional age (Tattersall *et al.* 2000). No small mammals were caught in grazed comparison plots and this is likely to be due to both perceived and actual increased predation risk where there is less cover (Jacob & Brown 2000) rather than direct competition for food resources from the large grazing mammals (Moro & Gadal 2007).

Mowing of the crops in spring had the immediate effect of reducing small mammal numbers, although as this intervention occurs at a time when populations are usually at their lowest, cause and effect may be difficult to separate. However, as a field of *Phalaris* at 'PP' ('PP2') was mowed in September for a separate study (ADAS Field to Farmer Project: late autumn grazing study), it was possible to identify the effects of mowing at a time when small mammal populations are rising. By December, the September-mown *Phalaris* ('PP2') had only reached a height of 10 cm, compared to 122 cm in the uncut field ('PP1'). Corresponding small mammal numbers in December were highly significantly different between the two fields, with a total of 3 per 100 TN in 'PP2' and 55 per 100 TN in 'PP1'. This implies that the current management of commercial biomass crops that are harvested in spring provides essential winter habitat for small mammals when their populations are at a peak. This is also the time of year at which no other arable crops are standing: winter-sown cereal fields are largely bare earth (Todd *et al.* 2000) and grass swards in pastoral areas are short.

Once the biomass grass crops are over two years old, aside from harvesting in spring, there is minimal disturbance throughout the rest of the year (Price *et al.* 2003), which could be particularly important to small mammal species that are sensitive to disturbance (Kotzageorgis & Mason 1997). It also means that the breeding season is not interrupted by harvesting as would be the case in annual cereal crops and this could be another key benefit to small mammal populations in the biomass grass crops.

Lack of pesticide inputs may also make biomass grass crops more favourable to small mammal populations. In a US study, densities of both gray-tailed voles *Microtus canicaudus* and deer mice *Peromyscus maniculatus* in alfalfa crops were depressed after the application of the insecticide azinphos-methyl (Schauber *et al.* 1997). It is also possible that the presence within the biomass crops of the omnivorous harvest mouse, which is susceptible to bioaccumulation of chemical toxins, is a good indicator of quality habitat (Bence *et al.* 2003).

3.4.7 Seasonal effects

Seasonal variation in total small mammal abundance followed the general patterns reported elsewhere (Schmidt *et al.* 2005; Tattersall *et al.* 2004; Kotzageorgis & Mason 1997) with peaks in winter and lowest numbers in spring. The negative correlation of small mammal abundance with increasing daily temperatures may be in part due to this seasonal effect. The seasonal variation was more pronounced in the biomass crops in Year 1, although there was also a winter peak in numbers in the headlands. This suggests that rising numbers within the biomass crops were due to successful breeding rather than immigration from the headlands, but further work involving capture-mark-recapture or radio-telemetry would need to be carried out to confirm this.

Two species were only caught at certain times of year: harvest mice only between the months of September and March and water shrews only between October and January. Trout (1978a) found similar results in both live trapping of small mammals and analysis of barn owl pellets for small mammal remains. In a study of deciduous woodland, Tanton (1965) suggested that wood mice may be difficult to catch in the summer months due to good food supplies changing behavioural patterns, including trap avoidance. Whether this is also true of species such as the harvest mouse and water shrew is unknown, but could explain their seasonal presence. Gurnell (1978) proposed that summer wood mouse populations were heavily influenced by the aggressive behaviour of males, which resulted in lower survival rates for juveniles in spring and summer compared to the autumn. Despite the mowing of the biomass grass crop and removal of the harvested material in spring, wood mouse numbers were still higher in summer than in spring in the biomass crops. This could have been due to reduced food resources in the crops making the wood mice more trappable, as implied by Tanton (1965), or may also have been a true reflection of higher numbers of wood mice able to exploit the resource.

With the highest numbers of small mammals trapped in the winter, and the fact that it took 10-12 months to trap the maximum number of small mammal species, it is clear that seasonal factors must be taken into account when censusing small mammals in biomass crops. Semere & Slater (2007a) only carried out small mammal trapping in spring and in September and therefore may have missed recording species such as the harvest mouse, (whose geographical range extends into the area they studied), and water shrews, which if present would also have been overlooked. Best practice dictates that trapping is not performed in unduly cold conditions (Gurnell & Flowerdew 2006), but with careful planning winter surveys can successfully be carried out.

3.4.8 Relationship with other crop characteristics

As already established, cover as protection from predators is vital for small mammals in an agricultural landscape (Jacob & Brown 2000) and the animals in this study followed the reported trend. Not only did total small mammal numbers correlate positively with crop cover in both crops, but individual species such as harvest mice in *Phalaris* and wood mice in *Miscanthus* also showed a response. A dense crop is likely to be particularly important to harvest mice (who showed the most significant relationship with percentage cover), as they spend a large proportion of their time foraging and breeding arboreally in the stalk zone throughout the summer (Trout 1978a).

By virtue of weedy patches between rhizome clumps in the early establishment phase, *Miscanthus* crops have the potential to support greater biodiversity through additional food resources such as weed seeds and the invertebrates that utilise the non-crop vegetation (Semere & Slater 2007b; Marshall *et al.* 2003). No correlation was found between the total number of small mammals and the percentage cover of weeds within the crops. However, harvest mice showed a negative correlation with weed cover in *Phalaris*, assumed to be due to their association with increased crop cover. Common shrews were associated positively with weed cover in *Miscanthus* and this may either be due to arthropod prey associated with the weeds, or the additional cover provided by them (Kotzageorgis & Mason 1997).

Increasing percentage cover of non-crop Gramineae was a predictor of field vole numbers in the *Phalaris* crops. Field voles consume a herbivorous diet (Lambin 2008) and although they may graze *Phalaris* during its early stages of growth, it is likely that non-crop grasses become an important component of their diet when the *Phalaris* grows taller and its leafy matter is out of their reach.

Certain associations between small mammal species both in relation to crop variables and other species were shown in PCA plots. In the biomass crops, wood mice and common shrews were positioned along the same axis, likely to be related to available cover. The two vole species showed varying associations in different crops and this is probably driven by the different microhabitats within the crops in relation to their differing requirements (Tew *et al.* 2000). Harvest mice occupied an opposite axis to the wood mice and this may be a result of competitive exclusion by the wood mice, which are competitively superior (Riordan *et al.* 2007).

3.4.9 Biomass crops in comparison with other agricultural land uses

The crop fields in this study varied in size, but all retained a traditional structure of crop, field margin (mostly 6 m uncultivated headland) and hedgerow. There are several features of biomass crops that make them potentially very conducive to wildlife. The uncultivated margins contain a large percentage of grasses, which when allowed to grow unchecked develop into tussocks, but also form a litter layer in which there are small mammal runs. Barn owls, which have declined in the UK over recent years are increasingly dependent on this type of habitat in which to hunt small mammals, as modernisation in farming practices has led to a reduction in good vole habitat such as rough grassland and hay meadows (Bond *et al.* 2005). The fact that the biomass field margins are predominantly 6 m rather than 2 m wide make them particularly conducive as the estimated optimal width of grassy margins based on barn owl hunting height and hearing range is 7 m (Askew *et al.* 2007). Significant shading can occur close to hedgerows, particularly unmanaged, tall ones, so it is conducive to the productiveness of the biomass crop to leave uncultivated margins between the crop and hedge. As set-aside is being reduced on a national scale, the importance of these margins may become increased, especially in predominantly arable areas. Retaining the existing hedge structure will also be of importance to small mammals, particularly after harvest in spring when hedges are likely to provide cover and food resources until the crop re-grows.

3.4.10 Arable crop comparison plots

The first year of small mammal trapping intended to compare biomass grass crops with the land use prior to crop establishment (mainly pasture) and did not include cereal crops even at the predominantly arable 'N' site due to lack of suitable crops to survey. However, by the intensive study in Year 2, spring barley and maize were available and therefore used, in order to give a better indication of small mammal presence on arable as well as pastoral land in comparison with the biomass crops.

The ubiquitous wood mouse was found in the maize and barley, both on the ground and in the aerial traps. Only one field vole was trapped in the barley and none in the maize. Although formal vegetation surveys were not carried out in the cereals, visually, it was apparent that weed management was more effective than in the biomass crops. The drilled barley grew in a dense manner with no visible bare earth. The architecture of the maize crop resulted in a dense canopy of leaves, shading out all but a few weeds growing in the otherwise bare soil around the stems. With architecture more like dense grassland, the barley appeared to be a more suitable habitat for the needs of the field vole than the maize. The lack of low vegetation in the maize would also have resulted in less available food for the herbivorous vole, however the climbing skills and wider diet range of the wood mouse mean that more food would have been available to it in the maize. With the abundance of wood mice in the maize, it is perhaps surprising that no bank voles were found there.

Use of arable land by small mammals has been well reported (Heroldova *et al.* 2008; Tew *et al.* 2000; Todd *et al.* 2000; Tew & Macdonald 1993; Green 1979), but very little work has been done on maize. Although it is an annual arable crop, maize plant architecture is more like *Miscanthus* than any other cereal and a comparison between the two could be revealing. Bilenca *et al.* (2007) reported higher trapping success in 'weedy' (≥ 50% cover) maize compared to maize with very few weeds in

Argentina. However when compared overall with soybean crops, there was no difference in small mammal abundance in the two crops, leading the authors to conclude that their numbers were determined by microhabitat rather than specific crops, and this concurs with the findings of Tew *et al.* (2000).

3.4.11 Comparisons with woody biomass crops

Some parallels are seen between the characteristics of the small mammals found in perennial grass and woody biomass crops. Fry & Slater (2009) also found the wood mouse to be the most abundant species in willow coppice. As with Year 1 results from the grass crops, they also found that the willow contained higher numbers of small mammals than the headlands and hedges. However, the species present in the willow was restricted to the wood mouse, yellow-necked mouse, bank vole and field vole. Common and pygmy shrews were only caught in the headlands and hedgerows and they found no evidence of the harvest mouse or water shrew. One of the willow coppice sites was within 3 km of the 'N' grass crop (albeit across the Eastern Cleddau river) and therefore had the potential to contain the same species. The presence, therefore of eight species in the grass crops suggests that *Miscanthus* and *Phalaris* provide a more favourable crop habitat for small mammals than willow coppice.

3.4.12 Conclusions

In conclusion, biomass grass crops have been demonstrated in this chapter to be widely used by small mammals. Although the hedgerows contained higher abundance of small mammals, *Phalaris* crops contained the highest diversity. A Biodiversity Action Plan priority species, the harvest mouse was abundant in the *Phalaris*, and was also found in lower numbers in the *Miscanthus*. Both biomass crops contained higher diversity and abundance of small mammals than cereal crops such as spring barley and maize. The agronomy of these perennial grasses within the traditional field structure where uncultivated headlands and hedgerows

are maintained are therefore likely to have a positive rather than negative effect on small mammals through the provision of additional habitat and food resources.

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CHAPTER 4

THE HARVEST MOUSE *MICROMYS MINUTUS* IN BIOMASS GRASS CROPS

Abstract

The harvest mouse *Micromys minutus* is through to have declined in abundance in recent years, and as a Biodiversity Action Plan (BAP) species, national effort is being put into its conservation. Harvest mouse presence was detected during the small mammal surveys in biomass crops at the Pembrokeshire (Wales, UK) site, and more intensive monthly surveys were therefore carried out for a further year at the site. The aim was to better understand the harvest mouse population in and around the biomass crops, through the use of a capture-mark-recapture programme and the recording of biometric data.

In addition to the live-trapping, searches for above-ground nests were carried out, and barn owl pellets collected within close proximity of the biomass field were examined for harvest mouse remains. Harvest mice were only captured within the two biomass crops, although nests were found in hedgerows nearby as well as in the *Phalaris*. No harvest mice were found within the adjacent barley or maize fields. Within the biomass crops, harvest mice demonstrated a distinct preference for *Phalaris*, although they were also trapped in small numbers in the *Miscanthus*. Harvest mice trapped in *Miscanthus* were more likely to be males than females. Some of the Longworth traps were set elevated into the stalk zone and these were more likely to contain females than males. The weights of male harvest mice in autumn were significantly lower than those recorded in winter or spring. In conclusion, biomass grass crops, particularly *Phalaris* are considered to be good habitat for populations of harvest mice.

4.1 Introduction

4.1.1 Post-glacial history and distribution of the harvest mouse

During the last Ice Age, genetic and fossil evidence suggests that the harvest mouse *Micromys minutus* Pallas (Rodentia) was only found in China. The species is thought to have spread back across northern Asia and Europe once the ice sheets retreated (Harris 1979a). This is confirmed by mitochondrial DNA analysis, which also suggests that there was considerable expansion and contraction of their range during the mid-late Pleistocene (Yasuda *et al.* 2005). Whether harvest mice reached Britain by natural dispersion across a land bridge from the continent or were subsequently introduced by human actions was for some time unclear (Harris 1979b), although a recent discovery in the UK of specimens from the early postglacial period suggests they should be classed as truly native (Trout and Harris 2008).

The first observations on the harvest mouse in Britain were published by Thomas Pennant in 1766, but a formal description was only published later by Pallas in 1771 (Harris 1979b). By the end of the nineteenth century, the harvest mouse had been reported in most English counties and eastern Scotland, with some records appearing to result from the spread of the species into previously un-colonised areas as a result of accidental transport with hay and cereals (Harris *et al.* 1995). There were also some records of harvest mice in North Wales by the beginning of the twentieth century (Harris 1979a). Even at this point there was concern that numbers in the UK were declining and at the time this was attributed to advances in the design of reaping machines causing high mortality during harvest. However, Harris (1979a) advised caution in assuming a decline, as the lack of accurate records and changes in agricultural practices to a more mechanised approach make population changes difficult to infer.

4.1.2 Morphology

The harvest mouse is the smallest European rodent, characterised by russet-orange fur dorsally, with a sharp delineation to white fur underneath. It has a blunt muzzle, small furry ears and a long, prehensile tail measuring approximately the same length as the head and body combined (Harris 1979b). The head-body length ranges from 50-80 mm, tail from 50-70 mm and body weight from 5-11 g (Macdonald and Barrett 1993). The harvest mouse is well adapted to a life climbing amongst grass and cereal stems as it has a proportionally light skeleton, its tail is used extensively and it has an opposable outer toe on the hind foot which allows it to firmly grip vegetation stems (Harris 1979b). Climbing skills develop rapidly in the young during the short lactation period of 15-16 days and prehensile use of the tail develops by the time the pups are 11 days old (Ishiwaka and Mori 1999).

The small size of the harvest mouse combined with its large surface area to volume ratio of 4.9 (Trout 1978b) and its active arboreal lifestyle means that it requires a high calorific intake equivalent to that of a 20 g mouse *Apodemus* spp. or vole *Microtus* spp. (Harris 1979b). However, as it is able to select food with higher energy per volume such as seeds, even this high intake is far less than that required by similarly sized shrews *Sorex* spp. which are restricted to water-rich (and therefore less energy-dense) invertebrates (Harris 1979b). Although generally more nocturnal, the harvest mouse is active for short periods every two to three hours, with peaks at dawn and dusk (Harris 1979b).

4.1.3 Life-history and breeding biology

The lifespan of the harvest mouse is short, with a maximum age of 18 months recorded in a wild animal (Macdonald and Barrett 1993). The breeding season is usually from May to October, but may extend to December in warmer, drier years with most litters being born in the months of August and September (Harris 1979c). Females are sexually mature at eight weeks old and can produce from three to

seven litters per year, each containing between three and eight young (mean 5.4 ±0.16, (Harris 1979c)) with a short gestation period of 19 days (Harris 1979b). In captivity, a maximum of nine litters has been recorded for a single female (Trout 1978b). This rapid breeding pattern can result in four generations successfully reproducing within one breeding season (Trout and Harris 2008).

The harvest mouse is the only small mammal to weave above-ground nests from shredded grass blades (Trout and Harris 2008). The spherical breeding nests of 6-10 cm diameter are supported by grass stems or the stems of shrubby species such as blackthorn *Prunus spinosa*, bramble *Rubus fructicosus* or hawthorn *Crataegeus monogyna*, at a height of between 30 and 60 cm above ground level (Macdonald & Barrett 1993). A new nest is built for each litter (Trout and Harris 2008). Harvest mouse pups are born blind with un-differentiated digits. They develop rapidly, with eyes opening at 8 days old and they are able to climb stems and walk weakly on flat surfaces at 9 days old (Trout 1978b). They start to make excursions outside the nest from 11 days old and by 16 days old are chased away from the nest by the mother (Trout 1978b).

In Britain, litters found in harvest mouse nests across the whole breeding season had an average mortality rate of 12% – usually involving loss of the whole litter rather than the death of a proportion of the individuals within it. This increased to 80% in autumn litters, which are more prone to climatic influences such as heavy rainfall and cold temperatures (Harris 1979c).

The harvest mouse is reported as being difficult to capture from late spring to late summer (Trout 1978a) which is believed to be due to behavioural changes during the breeding season (Trout, personal communication). Where animals were caught in summer, they tended to be juveniles rather than adults (Trout 1978a). Similarly, Trout (1978a) and Buckley (1977) found a corresponding seasonal

absence of harvest mouse remains in barn owl *Tyto alba* pellets during the summer. It is possible that some of these behavioural changes involve less time spent at ground level, since the success of summer trapping can be increased slightly through the use of aerial traps (Sibbald *et al.* 2006).

4.1.4 Feeding ecology

Harvest mice are omnivorous, with a varied diet including seeds, cereal grains, young leafy shoots, insects, fruits, berries and fungi, and even cannibalisation of injured or dead conspecifics has also been reported (Harris 1979b). The harvest mouse has been recorded eating bird eggs, for example from the nests of reed warblers *Acrocephalus scirpaceus* in reedbeds (Honza *et al.* 1998). Diet changes seasonally. In autumn and winter, Russian harvest mouse stomachs contained predominantly grass and cereal seeds, while as spring progressed into summer, a higher proportion of green matter and insects were consumed (Trout 1978b). As the diet is partly insectivorous, harvest mice are vulnerable to the effects of pesticides as a result of bioaccumulation of toxins from contaminated prey (Harris *et al.* 1995).

4.1.5 Habitat use

Traditionally, the harvest mouse has been associated with cereal fields, spending the summer in the stalk zone of grain crops and moving into the hedgerows after harvest. During the winter, it forages at ground level and is therefore more easily caught in Longworth traps at this time (Harris 1979b).

Surveys undertaken in the 1970s found most harvest mice along linear features such as field margins, ditches, verges and hedges, while their presence in cereal crops was less common (Harris *et al.* 1995). Moore *et al.* (2003) also reported a preference by the harvest mouse for arable field margins rather than the crops themselves.

Tall, dense grassy areas, patches of brambles, reedbeds and ditches are favoured (Trout and Harris 2008), as well as areas of sedge and litter in fenland (Flowerdew *et al*. 1977). Harvest mice have been found in higher densities than wood mice *Apodemus sylvaticus* in new farm woodlands in the early stages after planting (Moore *et al.* 2003), but were not found at all in short rotation willow coppice in an area of Pembrokeshire where they have been trapped in other habitats nearby (Fry and Slater 2009).

Despite a strong connection with farmland, the harvest mouse has also been found in non-agricultural habitats including urban environments such as churchyards and gardens, where undisturbed areas of dense grass and forbs were present (Dickman 1986). When the M11 motorway was built in North Essex, UK, harvest mice rapidly colonised the embankments in the second year when tall grasses, willowherbs *Epilobium* spp., thistles *Cirsium* spp. and teasel *Dipsacus fullonum* were the dominant vegetation types (Harris 1979a).

Across its wider range, the harvest mouse inhabit bamboo clumps, maize and rice plants (Harris 1979b), as well as *Miscanthus* spp. in Japan (Hata 2011, Ishiwaka *et al*. 2010; Hata *et al.* 2010; Kuroe *et al.* 2007) and stands of *Phalaris arundinacea* and *Phragmites australis* in the Petite Camargue, France (Durrer *et al*. 2006).

4.1.6 Nest-building habitat selection

Breeding nests have been found in at least 36 species of grasses, with cocksfoot *Dactylis glomerata*, reed canary grass *Phalaris arundinacea* and common reed *Phragmites australis* being most commonly used (Table 4.1; Harris 1979a).

Table 4.1 Monocotyledonous plants used by harvest mice for nest building (from Harris 1979a).

Plant species	Percentage of nests built in each plant species
Cocksfoot	21
Reed canary grass	14
Common reed	10
Other monocotyledons	50 (of which 24% unidentified)
Cereals	5

A study of Polish reedbeds (comprised largely of *P. australis*) found that harvest mouse nest site selection varied according to vegetation structure and soil moisture levels. Within the reedbed, the factors most likely to positively influence nest building were smaller, sparser reed shoots and a high abundance of sedges *Carex* spp. and grasses, whereas where there were tall, thick reed stems and abundant herbaceous vegetation, nest occurrence was lower (Surmacki *et al.* 2005). These findings are similar to those from a study of harvest mice in grassland of different successional stages. Harvest mice preferred the early and ruderal successional phases where there was taller vegetation architecture and a greater mix of both annual and perennial grasses and forbs and a more closed ground cover (Churchfield *et al.* 1997).

In wetter areas of reedbed, (where the mean height of the reeds was greater), harvest mouse nests occurred at up to twice the height of those constructed in the reeds growing where the soil was drier and less likely to flood (Surmacki *et al.* 2005). More recently, Hata (2011) also reported that nest height in flood plains and marshes was related more to the height of the plant in which the nest was constructed, rather than the presence or absence of water at the base of the plant.

Habitat preferences appear to be broadly similar across the harvest mouse's geographical range: Hata *et al.* (2010) report that in Japan, the plant preferred by harvest mice for nest-building over all other perennial grasses was Amur silvergrass *Miscanthus sacchariflorus* of at least 120-160 cm height. In a further study of harvest mouse nests, *M. sacchariflorus* was the most commonly used nesting plant,

comprising 87% in flood-plain habitat and 57% on embankment habitat (Hata 2011).

Some agri-environment schemes include prescriptions such as the formation of "beetle banks" alongside arable crops, originally intended to provide a winter refuge for predatory beetles and spiders. However, the banks have been shown to benefit many other invertebrates, birds and small mammals due to the tussocky grasses planted within them, which provide shelter and feeding opportunities (Bence *et al.* 2003). In a comparison between these beetle banks and grassy field margins, Bence *et al.* (2003) found higher numbers of harvest mouse breeding nests in the beetle banks than in an equivalent area of field margin. They also noted that cocksfoot and thistles provided the majority of the supporting structure for the nests in beetle banks, whereas the absence of such tussocks in the field margins resulted in thorns such as hawthorn, blackthorn and brambles being preferred.

Non-breeding nests of around 4 cm diameter, used as shelter by non-breeding mice are also built throughout the year. During the winter, the harvest mouse often builds nests in the base of grass tussocks close to the ground, but also uses a wide variety of sites for nest building, from old bird nests to stacks of bales, walls and banks (Harris 1979b). A study in Japan surveyed land where farmers burn away the native grass *Miscanthus sinensis* and discovered that nest building at ground level commonly occurred after the burn, which was in the non-breeding season between September and March (Ishiwaka *et al.* 2010).

4.1.7 Predation, competition and survival

Harvest mice, and particularly the young, are included in the diet of many different predators: birds such as owls (Order Strigiformes), kestrels *Falco tinnunculus* and crows *Corvus* spp., as well as larger birds that are usually less likely to eat small mammals, such as pheasants *Phasianus colchicus* and blackbirds *Turdus merulus*.

Harvest mice are also eaten by a range of mammalian predators including foxes *Vulpes vulpes*, weasels *Mustela nivalis* and domestic cats *Felis catus*; as well by adders *Vipera berus* and toads *Bufo* spp. (Trout and Harris 2008; Nelson *et al.* 2005; Harris 1979b).

The harvest mouse suffers from competition with larger mammals, particularly browsing deer (Order Artiodactyla) in young woodlands (Flowerdew & Ellwood 2000). This can involve direct competition for food resources such as fruits, seedlings and herbs, or it may be less direct, through destruction of nesting habitat and cover (e.g. grazing of grasses and removal of scrub).

Ylönen (1990) attempted to quantify competition between the harvest mouse and the bank vole *Myodes glareolus* using 0.5 ha enclosures where food availability was controlled. Where there was only one food station available in each enclosure, the voles excluded the mice, leading to poor harvest mouse survival rates over winter and a slowed growth of the population during the next breeding season. However, where food supplies were numerous and distributed evenly throughout the enclosures, harvest mice fared as well as the voles, and the voles actively avoided the mice (Ylönen 1990). The author also conducted some laboratory-based trap-choice experiments and found that bank voles preferred to enter a trap containing the odour of another vole rather than a washed one or one that had previously contained a harvest mouse. The harvest mice showed neither preference nor avoidance of any trap odour, indicating that the mechanism of competitive exclusion of harvest mice by bank voles is primarily through food limitation, rather than by direct physical avoidance.

In some habitats, both harvest mice and wood mice use the available resources in a three-dimensional manner, by climbing vertically into the vegetation where they lead an arboreal existence, as well as spending time at ground level. Factors such as

the life history, larger size and lower energy requirements of the wood mouse mean that it is likely to be competitively superior over the harvest mouse in these arboreal niches that are not exploited by other small mammal species (Riordan *et al.* 2007).

4.1.8 Effects of land management

Stubble-burning after harvest can be devastating to populations of harvest mice, particularly where the field headlands are also affected. Other rodents have been observed to move out of the path of the fire ahead of the burn, but harvest mice appear not to do this, and subsequent examination of affected areas has suggested that this causes substantial mortality rates (Harris 1979a; Trout 1978a).

Habitat containing tussocky grasses suitable for harvest mice, can be found on road verges, but the time of year at which these are mown usually coincides with the peak of the breeding season and is therefore likely to result in mortality of any litters of young mice within the nest at the time (Harris 1979b). A study of the management of reedy ditches alongside agricultural land in The Netherlands found that mowing ditch sides in alternate years, rather than annually, led to higher numbers of harvest mice where the resulting reed vegetation provided cover over the winter (Huijser *et al.* 2001). Similarly, in their Japanese range, a change in the management of embankments to intermittent mowing of *Miscanthus sacchariflorus* resulted in a greater number of harvest mouse nests and an extended nesting period in comparison with embankments where regular mowing was carried out (Hata *et al.* 2010).

Agricultural management in Great Britain has changed dramatically in the last 50 years. For example, Chamberlain *et al.* (2000) report six-fold increases in silage production from 0.2 x 10^4 tonnes dry matter (t dm) in 1970 to 1.2 x 10^4 t dm in 1990. During the same period, hay production halved from 0.8 x 10^4 t dm to 0.4 x

10^4 t dm. Hay meadows are only cut once in late summer, when the grass is tall and has seeded, whereas silage is cut 2-3 times over the growing season, before the seed has set (Chamberlain *et al.* 2000). As a result, the hay meadows provide better habitat for the harvest mouse than silage swards.

Timing of harvest can also impact on harvest mouse populations in cereal crops. Winter cereals are generally sown between September and December to allow shoot emergence before the first frosts, then are harvested in July – August, coinciding with the peak of the harvest mouse breeding season. Spring cereals are sown in February and then harvested in August – September, allowing any existing harvest mouse populations time to breed before harvest (Harris *et al.* 1995). During the late-20th Century, there was a general switch towards winter-sown rather than spring-sown crops. The main reason for spring sowing of cereals was to aid weed control, as the physical process of ploughing the land in spring enabled destruction of any weeds that had germinated over the winter (Chamberlain *et al.* 2000). The advent of pre-emergent and grass herbicides has resulted in winter crops becoming more prevalent than spring ones: in 1965, the area of winter wheat in the UK was 5×10^5 ha, rising to 17×10^5 ha by 1995. Over the same period, the area of spring wheat fell from a maximum of 2.6×10^5 ha to 0.1×10^5 ha (Chamberlain *et al.* 2000). Despite the apparent advantage of spring crops for harvest mice, Harris (1979b) suggests that winter cereals could provide nesting habitat earlier in the season than would be possible in spring-sown crops, even if there is an increased risk of mortality for young still in the nest by the time that the winter crops are harvested.

Advances in arable mechanisation have led to a more uniform crop plant distribution, through drilling seed in rows directly under the soil surface. The older method of broadcasting seed onto the surface of the soil tended to produce uneven and sometimes dense patches of crop plants, which were deemed more suitable for harvest mouse nest building (Harris 1979b). These changes, and other

advances such as combine harvesters replacing reaping machines, were formerly thought to have had negative effects on harvest mouse populations. This is no longer believed to be the case, as the animals continue to inhabit crop fields established by drilling the seed (Harris 1979b). The harvest mice are thought to escape to ground level as the combine harvester passes, resulting in fewer mortalities within the harvester than was originally believed. Straw left lying on the ground by the combine harvester gives cover to the mice as they move to nearby hedgerows; although they are still vulnerable to avian predators during this time (Harris 1979b).

4.1.9 Population status

The current population and conservation status of the harvest mouse is unclear. It is thought that numbers have suffered declines in the last century, but survey data are scarce and casual sightings may have reduced with mechanisation of harvesting processes, which has physically removed humans further away from the crop than when harvesting was carried out by hand or by more basic machinery (Harris 1979b). There has, however, been sufficient concern at a possible decline for the harvest mouse to be listed as a UK Biodiversity Action Plan (UKBAP) species (Sibbald *et al.* 2006). It also appears on the International Union for Conservation of Nature (IUCN) Red List, although it is currently designated as a species of least concern due to its worldwide distribution as a common species, combined with the absence of any major threats (Aplin *et al.* 2008).

Local harvest mouse populations can fluctuate enormously, with climatic factors such as heavy rainfall and extreme temperatures being responsible for higher mortality rates than predation (Harris 1979b). There are also marked seasonal fluctuations; harvest mouse populations peak in November and reach their lowest numbers in February and March (Haberl & Krystufek 2003; Harris 1979b; Trout 1978a).

Harris (1979a), in conjunction with the Mammal Society, conducted a survey of harvest mouse presence across the UK between 1973 and 1977, by means of enlisting the general public to complete recording sheets. 1,205 record sheets were returned and the results are shown in Table 4.2. It should be borne in mind, however, that this survey relied on the enthusiasm of non-randomly distributed volunteers and therefore may not be a true reflection of harvest mouse distribution (Harris 1979a).

Table 4.2 Harvest mouse records from 1973-1977 courtesy of Harris (1979a).

Country	County	Number of records
England	53 Watsonian vice-counties	1167
Wales	Pembroke	4
	Monmouth	17
	Glamorgan	13
	Caernarvon	2
	Total	36
Scotland	Edinburgh only	2

Another major survey was undertaken by the Mammal Society in 1997, whereby sites previously known to have harvest mouse presence were searched for breeding nests. Of the original 800 sites monitored, a nest presence level of only 29% was present in 300 sites and suitable habitat for harvest mice was no longer present in 24% of sites (Flowerdew 2004). It is unclear as to the mechanism for this change, but it is possible that even small changes within previously suitable habitat could render it unsuitable for harvest mice.

Possible reasons for declines in harvest mouse numbers are thought to be related to loss of suitable habitat caused by a loss of hedgerows, removed in order to increase field sizes and agricultural intensification. Old-fashioned cereal varieties tended to have longer stems, which were easier to handle during harvest with reaping machines, and the long straw had subsequent uses such as for thatching roofs. However, these long-stemmed varieties were prone to "lodging", where the stems

bend or break when subjected to heavy rain or wind, resulting in flattened areas of the crop. These flattened areas remain damp and are then difficult to harvest, as well as resulting in reduced grain quality. For this reason, shorter-stemmed cereal varieties are now favoured by farmers due to their increased resistance to lodging, and these may not provide adequate height for the building of breeding nests by harvest mice (Harris *et al.* 1995). In the 1940s and 1950s, harvest mice were still found in high numbers in the traditional ricks where cereals were stored prior to threshing (Harris *et al.* 1995; Venables & Leslie 1942), but the advent of the combine harvester ended the requirement for ricks as storage and therefore resulted in a further loss of winter habitat for the harvest mouse.

Predation by owls provides a further means of monitoring harvest mouse numbers, through analysis of pellet contents. A survey of barn owl pellets by the Mammal Society found that harvest mice accounted for 2.2% of barn owl prey species (Sibbald *et al.* 2006). Love *et al.* (2000) compared barn owl pellet contents between a first period of 1956 - 1974 and a second from 1993 - 1997. There was a marked increase in the median percentage frequency that harvest mouse remains were found between the two periods. This increase appears to contradict the findings over a similar period of time reported by Flowerdew (2004), although Love *et al.* (2000) suggest that loss of habitat has resulted in the remaining harvest mouse populations being at higher risk of predation. There was a rise in the percentage of arable sites in the pellet survey, from 37% in 1974 (of which 58% of sites where harvest mice were found were arable) to 60% in 1997 (of which 80% of harvest mouse sites were arable; Love *et al.* 2000). However, it is unclear whether there is a link between increasing area of arable sites and barn owl predation rates, or whether some other mechanism related to management is in effect. The 1997 survey also revealed harvest mouse presence in the North of England for the first time, but an absence from barn owl pellets from Wales and Scotland, where they had been reported in small numbers in the 1974 survey (Love *et al.* 2000).

A further study in 1997 investigated predation by the British domestic cat. Data were collected by means of questionnaires completed by cat owners, regarding the types of prey items brought into the home, therefore relying on the ability of householders to identify various small mammals. Approximately 30% of small mammal prey were categorised by householders as "mice" or "unknown mammal", but where harvest mice were identified and reported, they comprised around 2% of the total (Woods *et al.* 2003). Although this does not provide a definitive estimate of the numbers of harvest mice preyed on by domestic cats due to the identification difficulties and also the possibility of small prey being consumed *in situ* without being brought home, the proportion is similar to the 2.2% of prey items reported for barn owls by Love *et al.* (2000).

National population estimates of harvest mice are almost impossible to calculate, due to the lack of population density data, fragmented winter habitats and fluctuating local populations (Harris *et al.* 1995). However, Harris *et al.* (1995) used meta analysis to determine the ratio of wood mice to harvest mice (27:1), allowing them to arrive at a pre-breeding population estimate of 141, 500 harvest mice in England and 10,000 in Wales. The data used by Harris *et al.* (1995) came from a range of trapping and owl pellet samples, which in themselves showed great variation. These data are shown in Table 4.3 with further calculations from papers published since 1995.

Table 4.3 Analysis of different small mammal studies using ratios of wood mice to harvest mice as a means of estimating harvest mouse populations.

Type of study	Time of year	Ratio of wood mice to harvest mice	Source
Trapping in agri-environment prescriptions on arable farms (new farm woodlands, permanent set-aside, 2 m and 6 m margins). Ratio relates to total catch from all areas surveyed.	Nov-Dec	43:1 (2003) 69:1 (2004)	Askew *et al.* (2007)
Trapping in roadside verges (tripping weight set at 10g to reduce shrew captures, therefore also excluding all but pregnant female harvest mice from capture).	Aug-Sep	73:1	Bellamy *et al.* (2000)
Trapping in new farm woodlands, farmland and hedgerows.	Nov-Dec	1:1 (new woodlands) 9:1 (farmland) 61:1 (hedgerows)	Moore *et al.* (2003)
Barn owl pellet analysis.	Not known	15:1	Love *et al.* (2000)
Cat predation questionnaires.	Not known	11:1	Woods *et al.* (2003)
Meta analysis of methods below:	Not known	27:1 (total)	Harris *et al.* (1995)
Barn owl pellets		*9:1*	
Short eared owl Asio flammeus *pellets*		*81:1*	
Bottle samples		*37:1*	
Trapping samples		*58:1*	
Mean ratio from above studies		**34:1 ±9 (1SE)**	

4.1.10 Benefits of harvest mouse presence in agricultural crops

Even though the harvest mouse can cause some minor damage to yield when found in cereal crops, its presence could also be beneficial as pests such as wheat aphids are included in its diet (Harris 1979b). Indeed, field evidence for control of crop pests by harvest mice come from a Japanese study (Ishiwaka & Masuda 2008), in which experimental enclosures of Guinea grass *Panicum maximum* suffered less leaf damage from introduced armyworm *Mythimna seperata* caterpillars where harvest mice were present and this effect may also occur in crops containing native British pest species.

The broad diet of the harvest mouse, which includes invertebrates, means that it is vulnerable to the effects of agrochemicals and this has prompted the suggestion that its presence can therefore be used as an indicator of good quality habitat within an arable setting (Bence *et al.* 2003).

4.1.11 Aims of the study

Initial findings in Year 1 (Chapter 3) in crops of reed canary grass *Phalaris arundinacea* and *Miscanthus* x *giganteus* suggested that harvest mouse presence at site 'N' was predominantly in and around the *Phalaris* and the north hedge adjoining it, as determined by the presence of above-ground nests and live captures (Figure 4.2). The primary aims of this study were therefore to:

1. Widen the survey area at site 'N' and intensify the trapping sessions in order to pinpoint the distribution and movement of harvest mice around the *Phalaris* and *Miscanthus* crops,
2. Determine whether harvest mice were also present in the adjacent hedges and cereal crops,
3. Analyse seasonal trends in harvest mouse presence in the crops and surrounding habitats (if present),

4. Assess if there was evidence of breeding in the different crops and surrounding habitats ,
5. Assess characteristics of the crop/non-crop vegetation in relation to harvest mouse presence, and
6. Investigate the biology of the harvest mice present in the biomass crops by describing variables such as weight, sex etc.

4.2 Materials and methods

4.2.1 Traps

Longworth live traps were used as described in Chapter 3. The trap-door treadles were adjusted to maximum sensitivity in order to increase the likelihood that the light weight of the harvest mice would trigger the trapdoor mechanism. This also increased the chances of catching shrews and therefore extra provision of live food was made to prevent shrew mortalities. The traps were provisioned with mixed seed and live mealworms (*Tenebrio molitor* larvae) and filled with bedding hay to ensure that any animals trapped had plenty of food and warmth until the traps were checked at dawn and dusk (with additional midday checks in summer). During hot weather, pieces of carrot were added as a moisture source and traps exposed to the sun were shaded with pieces of Hessian sacking.

Figure 4.1 Longworth traps suspended on tripods in *Phalaris* (left) and barley (right).

Tripods were constructed from 1 m bamboo poles wired together, with a slightly sloping platform of 5 mm plastic mesh attached approximately 40 cm above ground level. Once both cereal and biomass crops had reached a height of 50 cm, the

locations of Longworth traps along the transect were alternated between ground level and elevated positions. The elevated traps were placed on tripods so that the entrances were in contact with the vegetation in an effort to target harvest mice dwelling in the stalk zone (Figure 4.1).

4.2.2 Transects

The locations of the trapping transects are shown in Figure 4.2. Transects were approximately 40 m in length and ten Longworth traps were set approximately 4 m apart along each transect line. Transects were originally laid at 20 and 100 m from the same crop edge that was used in Year 1 into *Miscanthus* 1 and the *Phalaris* crops. However, it became apparent that in order to assess the wider distribution of harvest mice throughout the field, trap lines needed to be increased to include a transect nearer to the south hedge (180 m), and all three equivalent distances in the slightly younger *Miscanthus* 2. A line of traps was also positioned in each of the four surrounding hedgerows and on the other side of the north hedge bordering the barley field. For the first three surveys, additional trap transects were set in the crop and hedgerow of the *Miscanthus* 3 field across the track from the main field. However, these were suspended after harvest of the biomass as no harvest mice were trapped there during the time-span in which they were trapped in the main field and the resulting spare traps were used to increase coverage of the main field as described above. Additionally, trap lines were set in adjacent fields of maize and spring barley from when the crop had reached a height of approximately 20 cm, until harvested. In order to maximize access and minimize crop damage, these transects were located at 20 and 50 m from the edge of the crop and followed tram-lines (sparse crop growth along the parallel narrow lines made by tractor wheels during crop management) where possible (see Figure 4.2 for transect locations and Table 4.4 for descriptions and numbers).

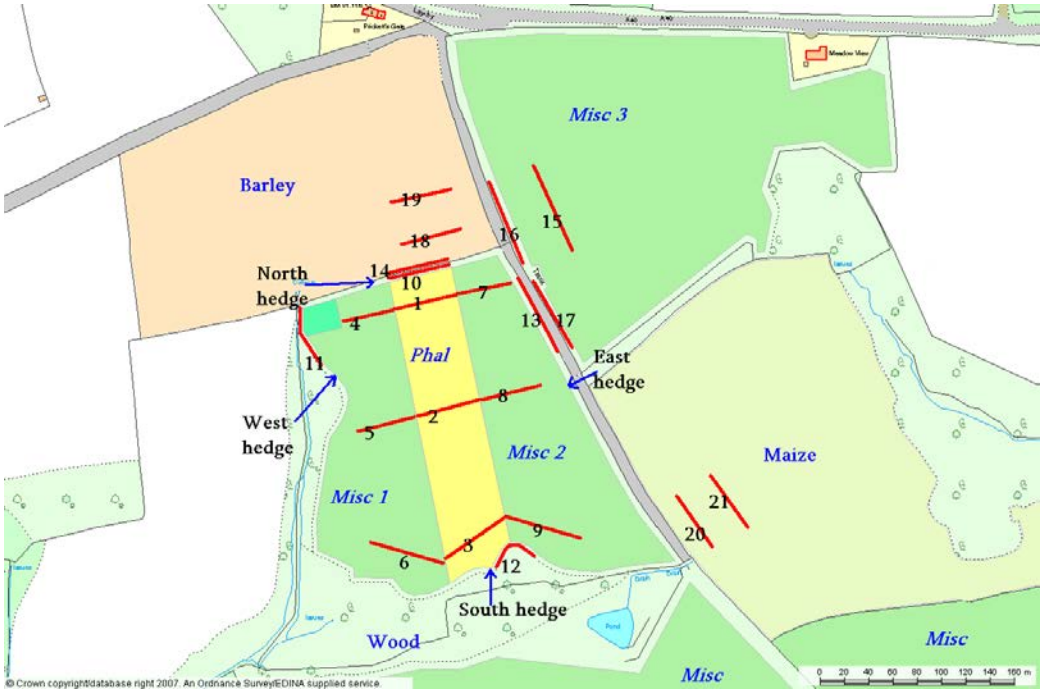

Figure 4.2 Positions of the transects within the different crops at site "N" (bold red transect lines show approximate position and length).

Monthly trapping was performed at monthly intervals (for dates see Table 4.5), with the traps left in position for 48 hours. The traps were initially set up by midday on the first day, and checked at each dawn and dusk, with additional midday checks during long summer days following practices recommended by Gurnell & Flowerdew (2006).

Table 4.4 Description of transects used for Longworth trapping, indicating distances into the crops from the edge (m).

Transect no.	Location (distances indicate position relative to the crop edge)
1	*Phalaris* 20 m (previously established)
2	*Phalaris* 100 m
3	*Phalaris* 180 m
4	*Miscanthus* 1 20 m (previously established)
5	*Miscanthus* 1 100 m
6	*Miscanthus* 1 180 m
7	*Miscanthus* 2 20 m
8	*Miscanthus* 2 100 m
9	*Miscanthus* 2 180 m
10	North hedge (main field)
11	West hedge (main field)
12	South hedge (main field)
13	East hedge (main field)
14	Barley field hedge
15	*Miscanthus* 3 20 m (field 2) (suspended after March harvest)
16	Hedge 1 (field 2) (suspended after March harvest)
17	Hedge 2 (field 2) (suspended after March harvest)
18	Barley 20 m
19	Barley 50 m
20	Maize 20 m
21	Maize 50 m

Table 4.5 Dates of trapping sessions in Year 2 at site "N".

Date	Comments
19-21 Feb 2009	Both crops intact
24-26 Feb 2009	Both crops intact
04-06 March 2009	*Miscanthus* 1 & 2 now stubble, *Phalaris* intact
23-25 March 2009	*Phalaris* now stubble. Transects expanded to include 180 m in *Miscanthus* 1 & 2 and *Phalaris*
08-09 April 2009	Only surrounding woodland and biomass bale stack trapped
21-23 April 2009	
19-21 May 2009	
01-03 July 2009	Added barley 20 and 50 m transects, tripods in use throughout
04-06 Aug 2009	Added maize 20 and 50 m transects
02-04 Sept 2009	Barley now stubble
29 Sept – 01 Oct 2009	
27-29 Oct 2009	Maize now stubble
24-26 Nov 2009	*Miscanthus* traps taken off tripods and placed at ground level as wind and crop movement causing traps to fall off tripods
(05-07 Jan 2010)	*Intended survey not carried out due to extreme winter weather*
26-28 Jan 2010	*Miscanthus* 2 harvested, *Miscanthus* 1 and *Phalaris* still standing – final trapping survey
February 2010	Remainder of biomass crops harvested

4.2.3 Biometric measurements and marking for individual identification

Harvest mice were sexed, weighed and marked with a number code, by clipping the guard hairs of the dorsal fur in a unique pattern (Gurnell & Flowerdew 2006; Figure 4.3).

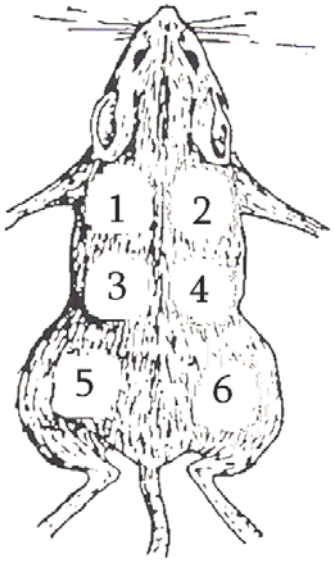

Figure 4.3 Coding system used for marking the harvest mice. Small areas of guard hair on the animal's back are clipped to expose the grey under-fur in the numbered locations to produce the individual codes (adapted from Gurnell & Flowerdew 2006).

Available codes for the fur clipping ranged from 0001 to 3456 (see Figure 4.4), whereby the use of the numbers 1-6 once per code gave a total of 54 possible unique codes.

Harvest mice at the beginning of the coding system would have less fur removed than those at the end, where up to four areas of fur could be cut. This was of concern, as the insulation and waterproof properties of the coat could be compromised. As it was thought possible that no animals would be caught for a period of time over the summer during which the marks might disappear, it was decided that marking carried out before harvest in spring 2009 would include a prefix of 1 in all records. Animals caught after harvest would be marked from the beginning of the coding system again (therefore removing less fur) and a prefix of 2 would be applied to distinguish them from pre-harvest capture records. Therefore

the code for the first mouse caught in spring was HM10001 (Harvest mouse 10001) and the first in autumn was HM20001.

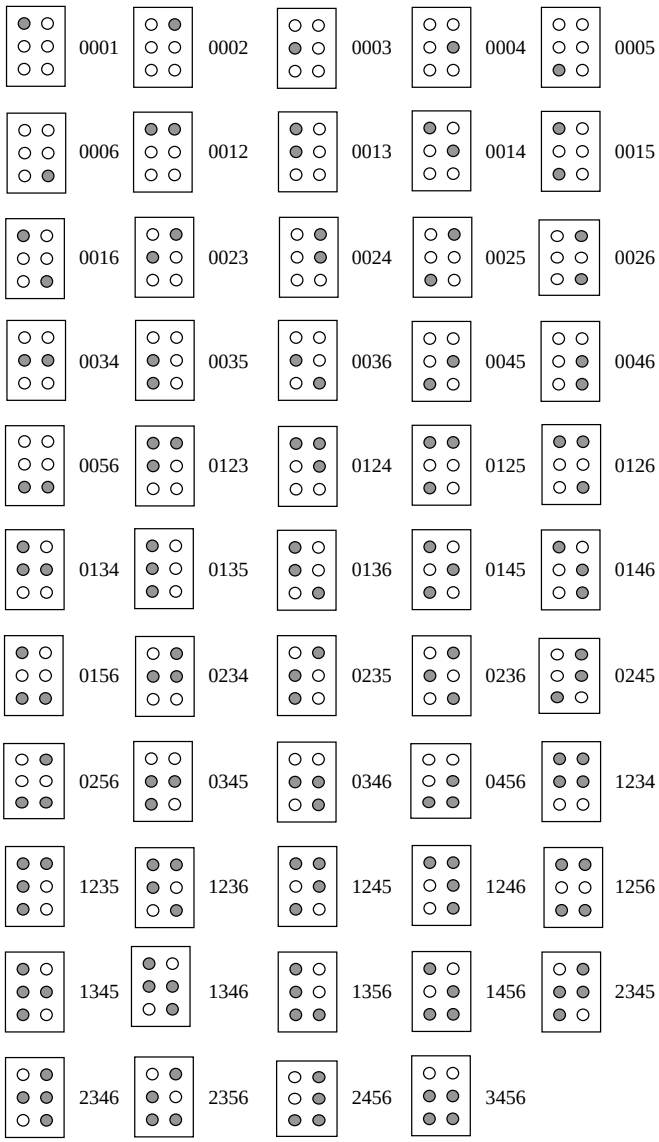

Figure 4.4 The dorsal marking positions available to create 54 unique codes, whereby each number is only used once at a time.

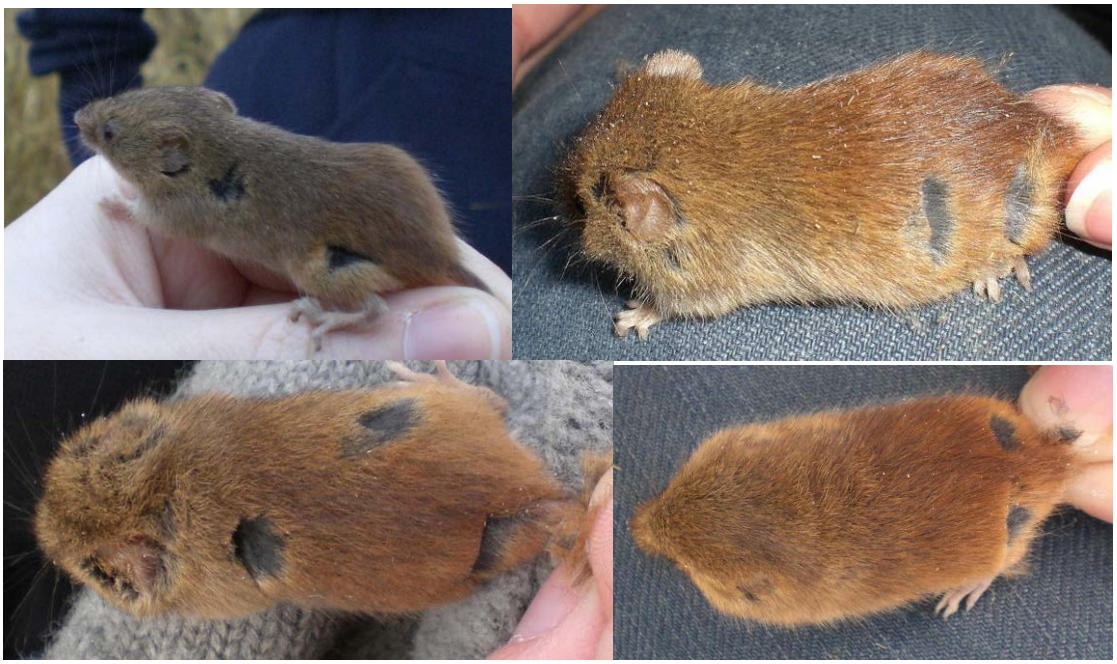

Figure 4.5 Photographs of the harvest mouse fur-clip marking system (clockwise from top left 0015, 0035, 0056 and 0145).

The harvest mice were then photographed (Figure 4.5 for examples) in order to aid recognition if recaptured and they were then released at the trap location. The intention was not only to record harvest mouse presence in the crops, but also to mark as many individuals as possible in order to track their movements around the study area.

4.2.4 Additional traps

During the first two surveys in February 2009, some of the hedge transects had an occupancy rate of 70-100%. At these occupancy levels, it is recommended to increase trap capacity (Gurnell & Flowerdew 2006). After harvest, it was thought that there might be migration from the crops into the hedges (Harris 1979b) and with the possible higher trap occupancy, trap numbers in the hedges were doubled for the survey immediately after harvest in March 2009, with two traps at each position instead of one.

It was not known exactly at what point in the year the harvest mice leave the stalk zone for an existence on the ground, although it is thought to coincide with the

die-back of vegetation in the autumn (Riordan *et al.* 2007). It was therefore decided that as soon as harvest mice were caught on the ground as well as in the aerial traps, an additional five traps per transect would be placed on the ground (one underneath each raised trap), in order to maximise chances of capture. This was only relevant for *Phalaris* (from the beginning of October) as no harvest mice were caught in elevated traps in the *Miscanthus* and due to problems with crop movement in windy conditions causing the traps to fall off the tripods, all 10 traps in *Miscanthus* were placed on the ground from November onwards. As harvest mice continued to be caught in the elevated traps in the *Phalaris*, the 15 traps per transect were used until the surveys ended.

4.2.5 Additional surveys

Trapping

Immediately after harvest of both grass crops was complete, no harvest mice were trapped in the stubble or hedges. In order to determine whether they had moved beyond the hedgerows, a 24 hour trapping period was carried out in the woodland scrub around the west and south edges of the field using 100 traps. In each line of 10 traps, 2 were elevated on a tripod in order that the entrance was accessible to any animals in brambles and other understorey vegetation. Traps were also laid in and around a pile of bales from the 2008 biomass harvest in a neighbouring field.

Nest searches

Every month, the crops and hedges were searched for nests. This was done by walking slowly through the crops whilst looking for the characteristic above-ground nests. Searches in the hedgerows consisted of examining clumps of cocksfoot and other grass tussocks as well as brambles and blackthorn.

Barn owl pellet analysis

A barn owl *Tyto alba* was seen hunting in the biomass crop field and two roosts were found within 1 km of the field (Figure 4.6). One of these was a hollow (but living) ash tree in a hedge-line and the other was in a barn (used for storage of wood and machinery, but little-used by humans) at the periphery of a group of farm buildings. From October to January (avoiding the owls' breeding season), these roosts were visited monthly and all visible pellets collected. It was apparent that the barn was not in regular use by barn owls at the time, as no new pellets were found after the initial collection, but the ash tree was observed to be in regular use and new pellets were found during some of the monthly collections. A total of 79 pellets and a large quantity of loose pellet debris were recovered from both roost sites for analysis of small mammal content. Pellets were soaked in luke-warm water and skulls and jawbones were separated from fur and other bones under a dissecting microscope. These were then identified to species using Yalden (2009) and a record was made of the number of skulls and lower left and right dentaries for each species. All pellets collected from the same site on the same date were analysed as a 'batch', although each pellet was dissected and counted individually. In order to calculate the actual number of each small mammal species per batch, the maximum number of either skulls, left or right dentaries in each batch was used (Love *et al.* 2000). Calculations were then made of the percentage of each species found at each roost site. It was not possible to analyse pellet contents by month as new pellets were not found on every visit and collections only took place from September to January. The age of pellets deposited in dry places can be estimated by certain characteristics of the pellet matrix (Ramsden & Ramsden 2002) but one end of the barn and the ash tree roost were exposed to rain, causing deterioration of the pellet matrix and rendering it impossible to estimate when they might have been deposited.

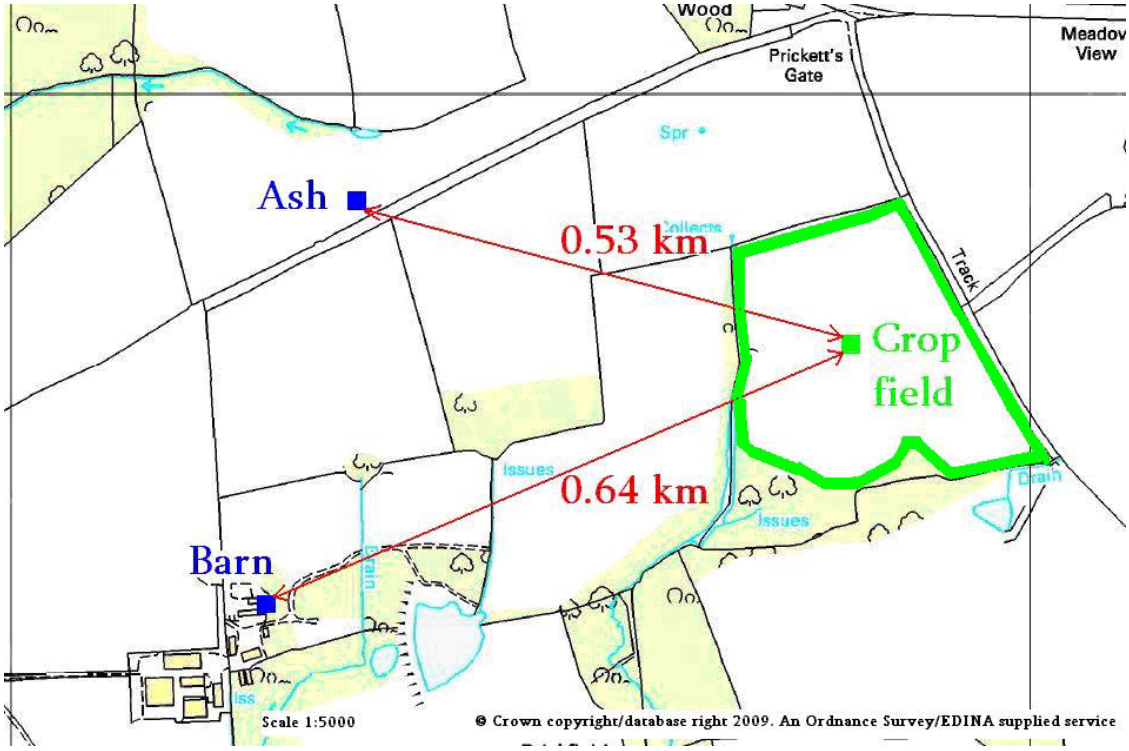

Figure 4.6 Map showing the two barn owl roosts from which pellets were collected for analysis, in relation to the biomass crop field.

Vegetation characteristics

Vegetation surveys were carried out once in late autumn 2009 in the *Phalaris* and *Miscanthus*. A 50 cm x 50 cm quadrat was placed at five regularly spaced locations along each transect and an estimation was made of percentage cover of all vascular plant species, litter and bare ground. Crop height was also measured by taking five stems at each quadrat location and recording the distance from ground level to the topmost leaf ligule.

4.2.6 Data analysis

Data were analysed using the statistical package STATISTICA 10.0 (StatSoft Inc). Normality of distribution was assessed using the Shapiro-Wilk test. Factorial or one-way Analyses of Variance (ANOVA) were used where data were normally distributed. Where non-Gaussian distributions occurred, it was impossible to achieve normality using transformations. In these instances, differences in harvest mouse abundance between the different crops, transects and time periods, as well as

sex and weight were tested using non-parametric Kruskal-Wallis tests. Generalized linear models (GLM) were used to describe relationships between harvest mouse abundance, crop characteristics and the abundance of other small mammal species, as well as describing factors relating to body weight and the height of trap in which they were caught.

Comparisons between trapping periods were made using a calculation of numbers of individual animals per 100 trap-nights (TN), where one TN represents one trap set for one night.

Abbreviations used in tables and figures are as follows: WM: wood mouse, HM: harvest mouse, BV: bank vole, FV: field vole *Microtus agrestis*, CS: common shrew *Sorex araneus*, PS: pygmy shrew *Sorex minutus*, WS: water shrew *Neomys fodiens* and HsM: house mouse *Mus domesticus*.

4.3 Results

4.3.1 Number of small mammal captures

The year-long period of monthly surveys between February 2009 and January 2010 comprised 3,860 trap nights across the biomass crops, cereal crops and hedges. A total of 1,598 captures of seven species of small mammal were made, shown in Table. 4.6. Results from the first night of trapping at each session are presented in Chapter 3.

Table 4.6 Total numbers and percentages of small mammal captures and in the 3,860 trap nights at site 'N' during the intensive survey.

	WM	HM	BV	FV	CS	PS	WS
Total captures in all habitats	809	85	400	38	199	35	32
% of small mammal catch	50.6	5.3	25.0	2.4	12.5	2.2	2.0
Total in *Miscanthus*	268	14	37	2	25	4	5
% in *Miscanthus*	75.5	3.9	10.4	0.6	7.0	1.1	1.4
Total in *Phalaris*	96	71	13	8	32	4	12
% in *Phalaris*	40.7	30.1	5.5	3.4	13.6	1.7	5.1
Total in both biomass crops	364	85	50	10	57	8	17
% in both biomass crops	61.6	14.4	8.5	1.7	9.6	1.4	2.9

A total of 69 harvest mice were captured 85 times. Two escaped before marking was possible, but the remaining 67 were fur-clipped with individual codes. Of these, 34 were females, 33 were males and four had juvenile pelage (greyer dorsal fur). One juvenile was found dead in a trap in November 2008 despite food remaining in the trap, but no further harvest mouse mortalities occurred in the survey year.

No harvest mice were caught during the additional survey of the woodland scrub and bale stack after the harvest of biomass in March 2009. Despite this, there was evidence of previous small mammal activity in the bale stack with small tunnels and some nests visible within the material, although it could not be determined which small mammal species had made the nests.

In comparison with estimates of harvest mouse populations from published work elsewhere, site 'N' contained a low ratio of wood mice to harvest mice, calculated as follows: 10:1 (all areas surveyed throughout the year), 5:1 (biomass crops only throughout the year) and 3:1 (biomass crops only during the months in which harvest mice were caught). When taking into account percentage cover of the biomass crops, transect location and other rodent species, a GLM explaining harvest mouse abundance showed a significant association (P <0.0001) between the abundance of wood mice with harvest mice (Wald statistic = 205.259, df = 1, Poisson distribution, log-link function). Scrutiny of the parameter estimate showed this to be a negative association (estimate = -0.021 ±0.002).

4.3.2 Crop preference and evidence of breeding

Harvest mice were markedly more abundant in the *Phalaris* than the *Miscanthus*, with the total number of captures standing at 71 and 14 respectively (including all recaptures). GLM analysis of harvest mouse abundance in relation to capture month, crops and transects showed this to be significant result (P <0.0001; Figure 4.7 and Table 4.7).

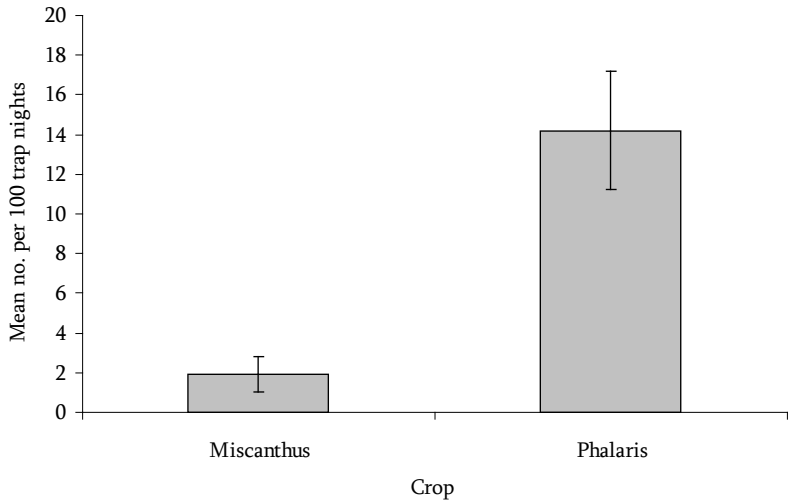

Figure 4.7 Mean numbers ±1 SE of harvest mice per 100 TN (trap nights) in both biomass crops between the months of September and March (the months during which harvest mouse captures were made).

Table 4.7 Results from a generalized linear model (GLM) describing variation in harvest mouse abundance in the two biomass crops, taking into account the month of capture and crop species (independent variables, all treated as fixed factors), using a log link function for a Poisson distribution.

	df	Log-likelihood	Chi - square	*P* - value
Intercept	1	-146.600		
Crop type	1	-122.595	48.0081	<0.0001
Month	6	-68.883	107.4249	<0.0001
Crop type*Month	3	-62.090	13.5869	0.004

There also appeared to be a difference in the distribution of the sexes between the *Miscanthus* and *Phalaris* cropped areas. Whilst numbers of males and females in *Phalaris* were not significantly different (Wilcoxon matched pairs test Z = 0.928, N = 71, $P = 0.353$), there were significantly more males than females in *Miscanthus* (Wilcoxon matched pairs test Z = 2.354, N = 14, $P = 0.019$). There were also significantly higher numbers of females in the *Phalaris* than the *Miscanthus* (Kruskal-Wallis H (1, N = 85) = 8.176, $P = 0.004$) and more males in the *Miscanthus* than *Phalaris* (Kruskal-Wallis H (1, N = 85) = 8.176, $P = 0.004$). These differences are plotted in Figure 4.8.

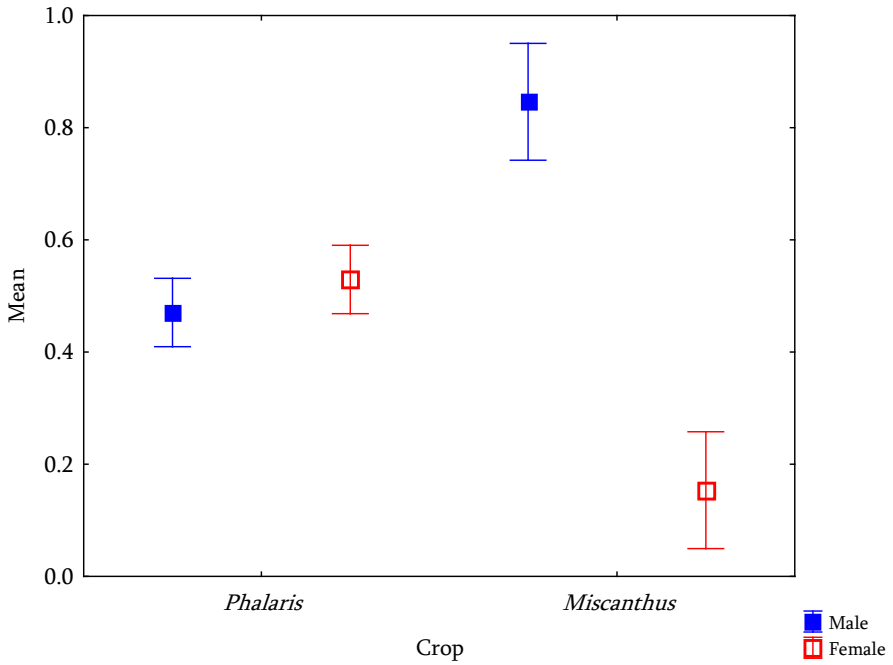

Figure 4.8 Distribution of male and female harvest mice in the two biomass grass crops. Values shown are mean per capture ±1SE.

None of the captured females appeared to be pregnant or lactating at the time of capture. Four of the harvest mice were considered to be in juvenile pelage and were therefore estimated to be <30 days old at the time of capture. A total of 18 breeding harvest mouse nests were found in the *Phalaris*, north hedge and the fence line between the barley field and the track (Figure 4.9), but only in winter 2008/09. No breeding nests were found in the winter of 2009/10. Where breeding nests were present in *Phalaris*, they were constructed from the crop leaves and were suspended in between *Phalaris* stems rather than any other non-crop plant. Nests found in the hedgerows were predominantly built in clumps of cocksfoot with three found suspended on bramble stems.

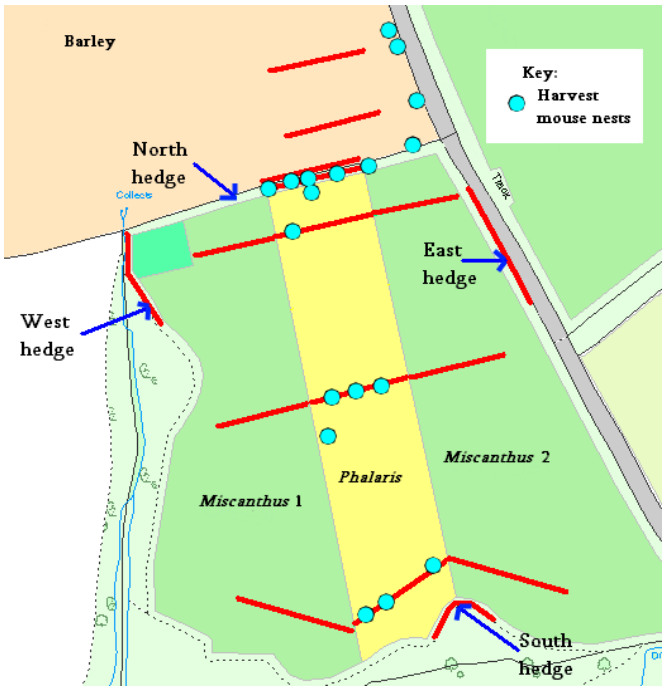

Figure 4.9 Map of the site "N" showing the distribution of harvest mouse nests (bold red transect lines not to scale). © Crown Copyright/database right 2011. An Ordnance Survey/ Edina Digimap supplied service.

4.3.3 Distance into the crops

The highest numbers of harvest mice caught within the crops tended to be found in the 20 m transects, followed by 100 m and 180 m although this was not a significant difference (Kruskal-Wallis H (2, N = 45) = 2.729, $P = 0.256$, Figure 4.10).

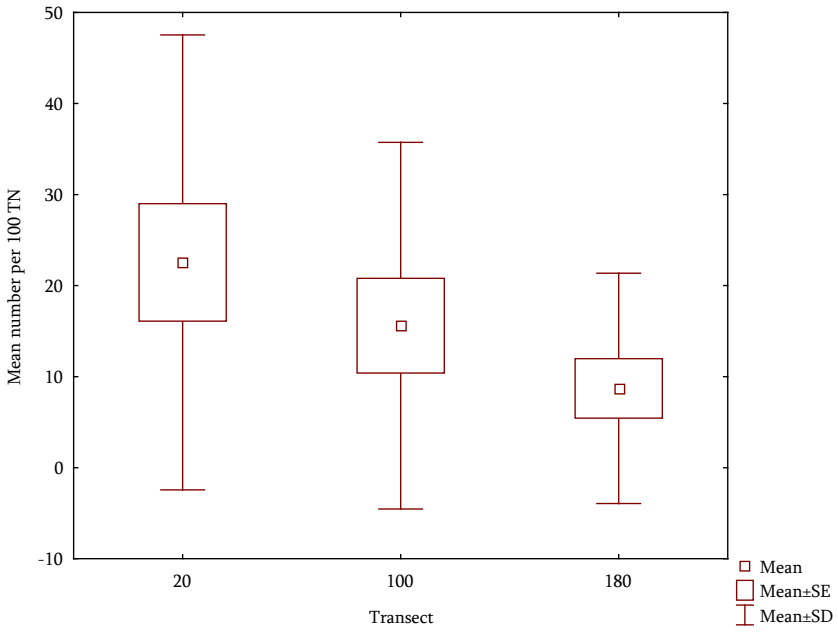

Figure 4.10 Mean number per 100 TN of harvest mice found in the transects at different distances into the biomass crops.

4.3.4 Times of day trapped

Mean time elapsed between trap checks throughout the day ranged from 13.5 trapping hours for the morning check, 5.5 hours for the midday check and 4 hours for the evening check. The highest numbers of harvest mice were caught in the morning (Table 4.8), but when these figures were adjusted to capture rate per hour, no significant difference existed between the different times of day in which the traps were checked ($F_{(4, 21)} = 0.660$, $P = 0.627$. There was also no significant difference between the sexes in terms of how many were caught in each time period ($F_{(4, 40)} = 0.792$, $P = 0.537$).

Table 4.8 Total and mean captures per trapping session and per trap hour of male and female harvest mice at different times of day in both biomass crops during the months in which they were captured (September – March). M = *Miscanthus*, P = *Phalaris.*

Time	Sex	Total		Mean ± SE		Mean per hour
		M	P	M	P	Combined crops
AM	Male	6	27	1.5 ± 0.9	3.0 ± 1.0	0.15
	Female	1	29	0.3 ± 0.3	3.2 ± 0.9	0.14
MID	Male	3	1	0.8 ± 0.5	0.1 ± 0.1	0.05
	Female	0	7	0	0.8 ± 0.4	0.08
PM	Male	3	3	0.8 ± 0.5	0.3 ± 0.2	0.10
	Female	1	4	0.3 ± 0.3	0.4 ± 0.2	0.08

Capture rates during the day (combined midday and dusk checks) increased during the winter, but this was not a significant effect (Figure 4.11).

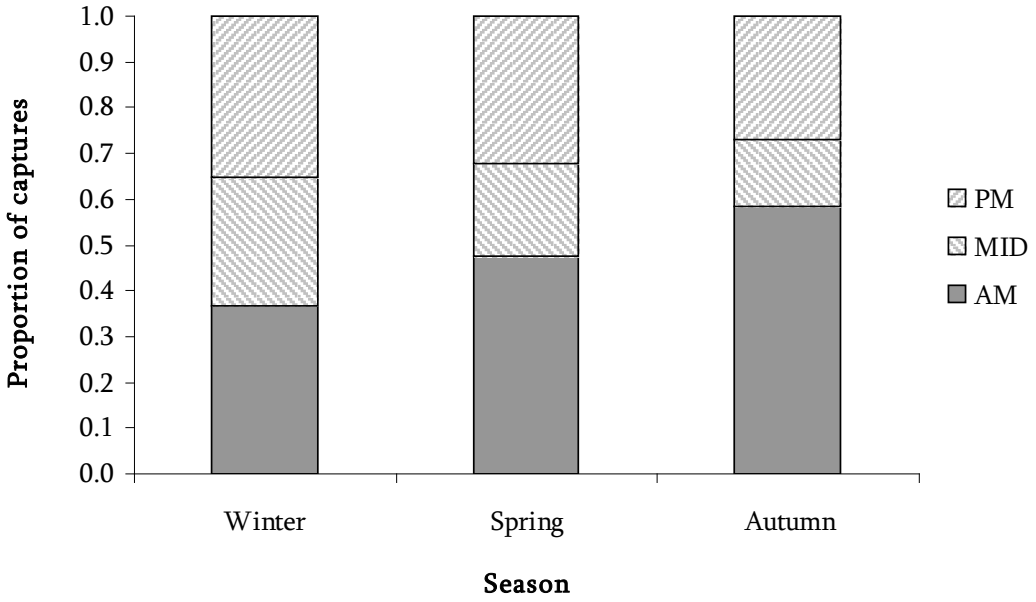

Figure 4.11 Relative proportion of harvest mouse captures at different times of day in the three seasons in which they were caught. Figures represent the number of captures per hour for the different times of trap check (AM = dawn, MID = midday, PM = dusk).

4.3.5 Recaptures

56 harvest mice were caught once only. Eleven were recaptured, representing 16% of the total (Table 4.9). One individual (HM10013) was caught seven times, and was found in the same trap in five out of six checks during one survey.

Table 4.9 Details of the number of times individually marked harvest mice were recaptured, dates of first and last capture and the biomass crop(s) where caught.

Individual ID	Sex	Date of first capture	Date of last capture	Times caught	Crops in which trapped
HM10003	M	20/02/09	26/02/09	2	*Phalaris* & *Miscanthus*
HM10004	F	21/02/09	25/02/09	2	*Phalaris*
HM10012	M	21/02/09	25/02/09	2	*Phalaris* & *Miscanthus*
HM10013	M	26/02/09	06/03/09	7	*Phalaris* & *Miscanthus*
HM10025	F	25/02/09	25/02/09	2	*Phalaris*
HM10026	M	25/02/09	26/02//09	2	*Phalaris*
HM10056	M	26/02/09	06/03/09	2	*Phalaris* & *Miscanthus*
HM20001	F	04/09/09	28/01/10	2	*Phalaris*
HM20005	F	01/10/09	26/11/09	3	*Phalaris*
HM20014	F	01/10/09	29/10/09	3	*Phalaris* & *Miscanthus*
HM20123	F	25/11/09	26/11/09	2	*Phalaris*

Of the eleven recaptured harvest mice, five were male and six were female. One (HM20005) was considered to be in juvenile pelage on first capture, but had moulted into an adult pelage by the time it was recaptured 56 days later.

Time from first to last capture ranged from eight hours (HM10025) to 146 days (HM20001). No animals marked in spring 2009 were captured later in the year.

Five harvest mice moved from one crop to the other: two from *Phalaris* to *Miscanthus* and three in the opposite direction. Apart from one, all other recaptures (both within the same or a different crop) were within the same distance from the crop edge. There was some movement along the transects themselves however, with eight of the eleven being caught in different trap positions when recaptured. Maximum distance travelled by any recaptured harvest mouse was approximately 85 m (HM 20014 – initially caught in *Phalaris* 20 m, subsequently in *Miscanthus2*, 20 m, and finally in *Phalaris* 100 m). Recaptured harvest mice travelled a mean distance of 12.5 ±6.1 m (median 4 m).

4.3.6 Body weight

Harvest mouse body weight varied significantly between seasons and this seasonal difference was sex-dependent, (Table 4.10).

Table 4.10 Results from a generalized linear model (GLM) describing variation in harvest mouse body weight taking into account sex and season, using a log link function for a normal distribution.

	df	Deviance	Resid. df	Resid. Dev	F	Pr(>F)
Null			75	60.222		
Season	22	19.728	73	40.494	21.613	<0.00001
Sex	1	1.9134	72	38.580	4.193	0.044
Season:Sex	2	6.633	70	31.947	7.267	0.001

Overall, male harvest mice were significantly heavier than the females (mean 6.49 ±0.15 g and 5.97 ±0.1 g respectively, Kruskal-Wallis H (1, N = 84) = 6.417, $P = 0.011$) as shown in Figure 4.12.

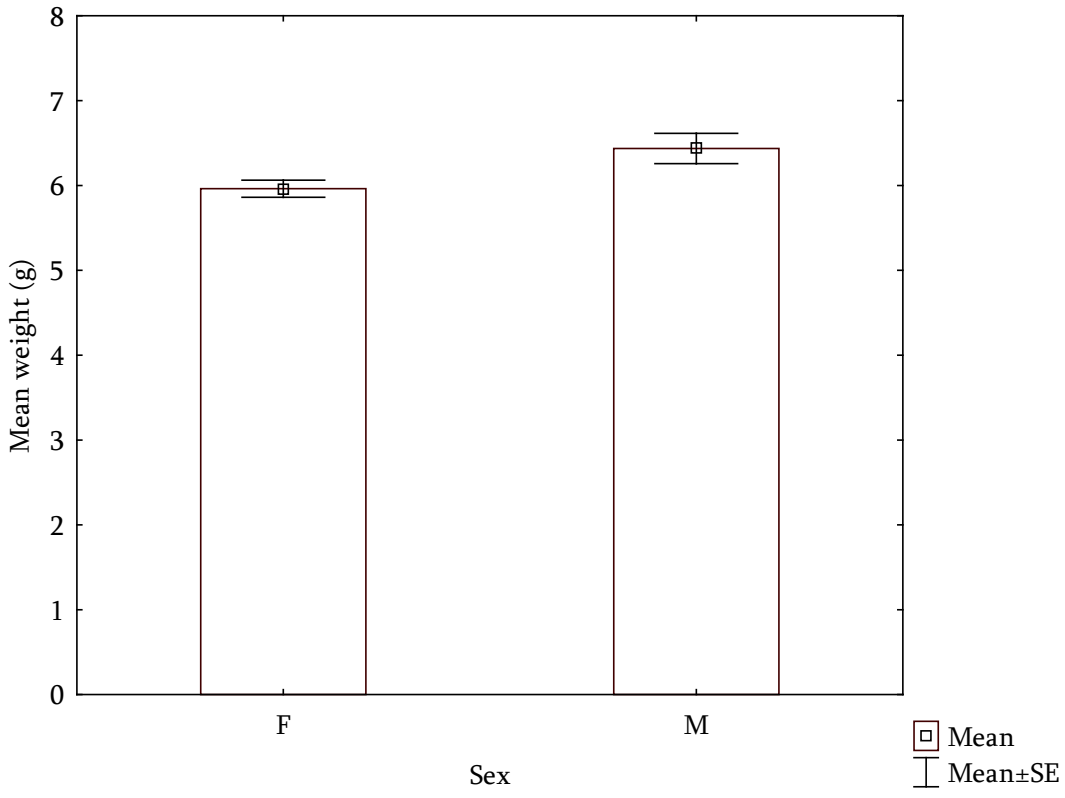

Figure 4.12 Mean body weights ±1SE of male and female harvest mice at site 'N'.

Scrutiny of the coefficient values from the GLM showed that the difference in body weight in males compared with females was greater in winter than in autumn (estimated seasonal change in the sex-difference in body mass 0.204 g, SE 0.057 g, t-value 3.598, $P < 0.001$). Male harvest mouse body weight was at its maximum in winter and lowest in autumn (Figure 4.13).

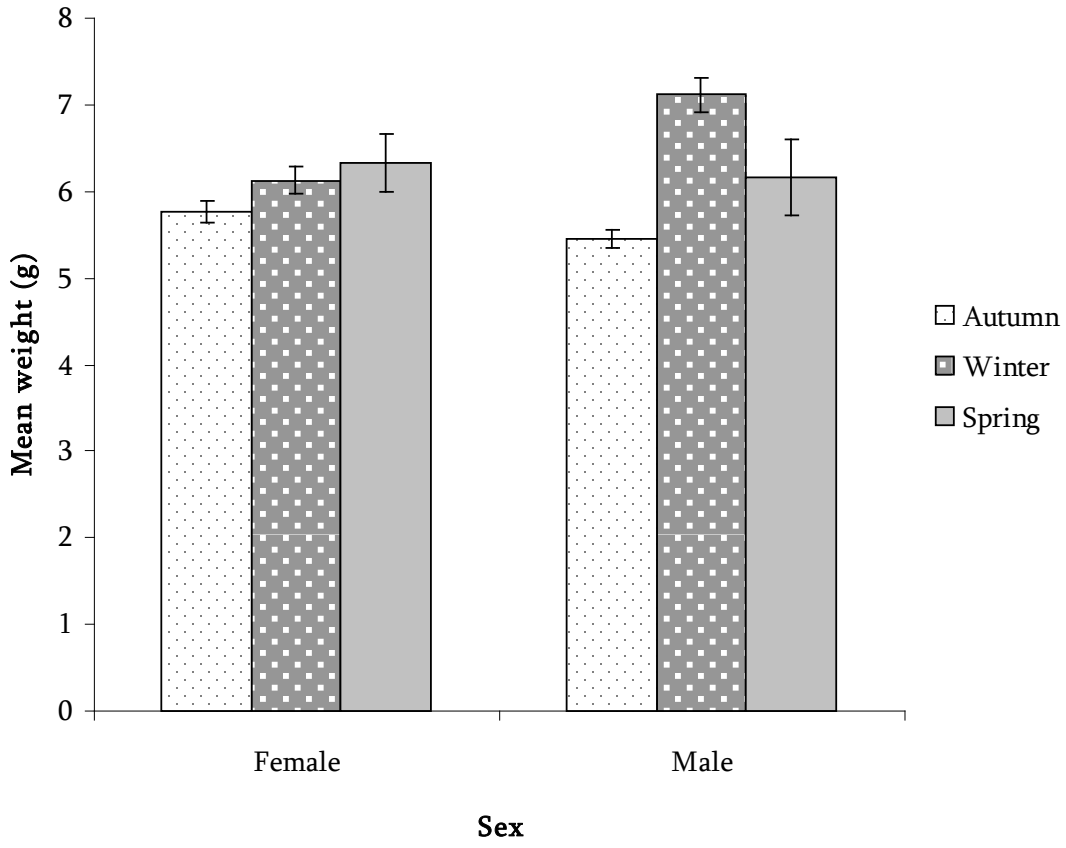

Figure 4.13 Seasonal changes in the body weight of male and female harvest mice. Values shown are mean weight (g) ±1SE.

There were no significant differences between the mean weights of harvest mice found in the two different biomass crops when individual sexes were taken into account (Table 4.11).

Table 4.11 Comparisons of mean body weights ±1SE of harvest mice in the two biomass crops. Results from a Kruskal-Wallis test for body weight differences between males and females in the same crop are shown with *P*– values.

Harvest mouse sex	Mean weight (g) in *Miscanthus*	N	Mean weight (g) in *Phalaris*	N	df	KW-H	*P* - value
Male	6.7 ±0.2 g	11	6.3 ±0.2 g,	25	1	1.360	0.244
Female	6.5 ±0.3 g	2	5.9 ±0.1 g	39	1	1.309	0.253

4.3.7 Seasonal differences in captures

In spring 2009, the final capture of any harvest mice was on 6th March. After a 6 month absence from the traps, the first individual caught in the autumn was on the 4th September 2009. The number of captures in the *Phalaris* showed no significant change during the seasons in which harvest mice were being caught. Due to the earlier harvest in February (classed as winter), *Miscanthus* showed an apparent absence of captures in spring.

Harvest mouse captures in January 2010 were lower than expected. Figure 4.14 shows predicted captures for that month based on the mean catch per 100 TN in February and November 2009.

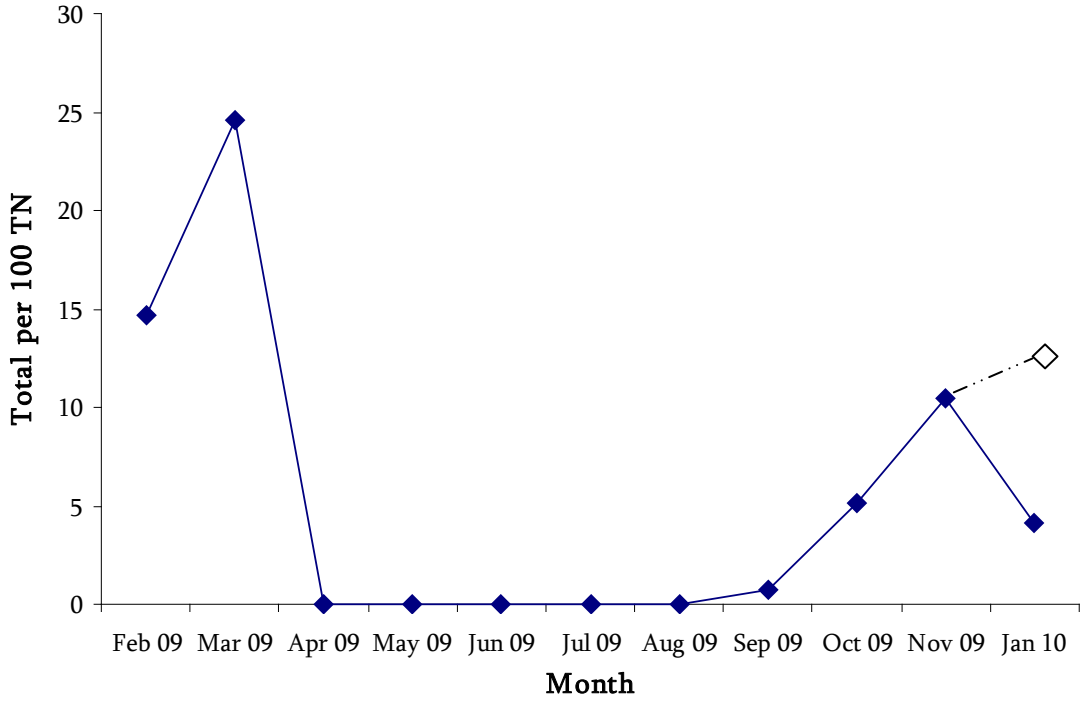

Figure 4.14 Harvest mouse captures per 100 TN for each monthly trapping session of the year-long survey. The dotted line and open diamond represent the predicted catch for January 2010 based on abundance in February and November 2009.

Other rodents also declined in number between November 2009 and January 2010, which was a particularly cold period, but all of the shrew species increased in abundance, although only in small numbers (Table 4.12).

Table 4.12 Declines and increases in total catch of the rodent and shrew species between the surveys in November 2009 and January 2010.

	November 2009	January 2010	Difference
Wood mouse	48	15	-68%
Harvest mouse	20	5	-75%
Bank vole	5	3	-40%
Common shrew	6	7	+17%
Pygmy shrew	0	2	N/A
Water shrew	7	8	+14%

4.3.8 Captures at different heights

Harvest mice were caught in the elevated traps in the *Phalaris* (a total of 26 captures, Table 4.13), but were not captured at all in the elevated traps in

Miscanthus. During the same period, 60 wood mice were caught in the *Miscanthus* elevated traps, more than in the elevated traps in *Phalaris*, where a total of 26 wood mouse captures were made.

Table 4.13 Total numbers of harvest mice caught in traps at the two different height levels within the two biomass grass crops for the duration that different height traps were used (May 2009 – Jan 2010).

Trap height	*Miscanthus*	*Phalaris*
Elevated	0	26
Ground-level	2	12

Numbers of harvest mice trapped in either the ground-level traps or those elevated on tripods in the *Phalaris* between September and January were compared (Figure 4.15). A total of 12 animals were trapped at ground level during that time-period, compared with 26 in the elevated traps, which was a significantly different result (Kruskal Wallis H (1, N = 24) = 5.932, $P = 0.01$). The first harvest mouse caught on 4th September was in an elevated trap, as were four of the five harvest mice caught in the final survey at the end of January 2010.

Significant relationships between the sex of the harvest mouse and the height of trap in which it was captured were also demonstrated. Females were significantly more likely to be found in elevated traps (Kruskal-Wallis H (1, N = 24) = 5.645, $P = 0.018$), but for males, no significant preference was seen between the two trap heights (Kruskal-Wallis H (1, N = 24) = 0.586, $P = 0.444$; Figure 4.16).

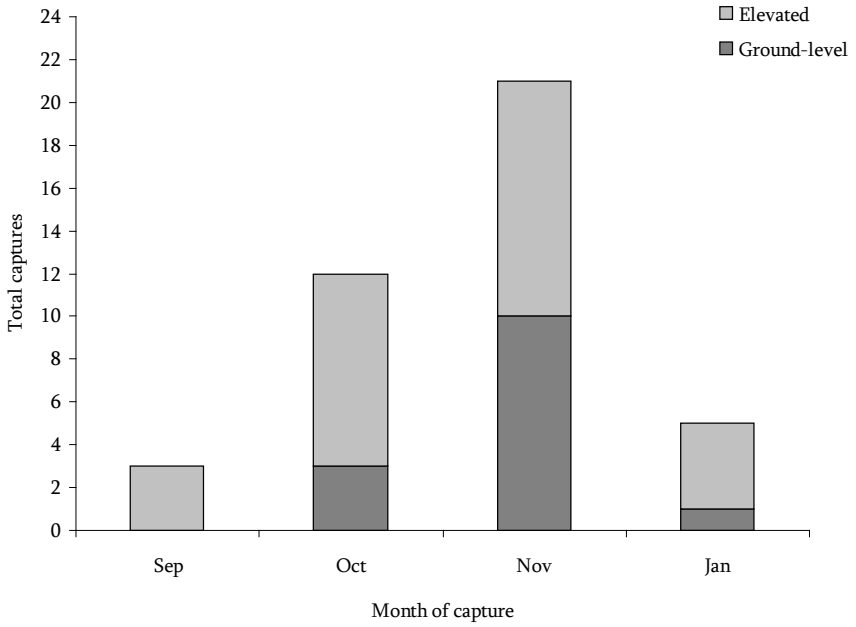

Figure 4.15 Seasonal changes in the numbers of harvest mice caught in elevated and ground-level traps (Sep 2009 – Jan 2010).

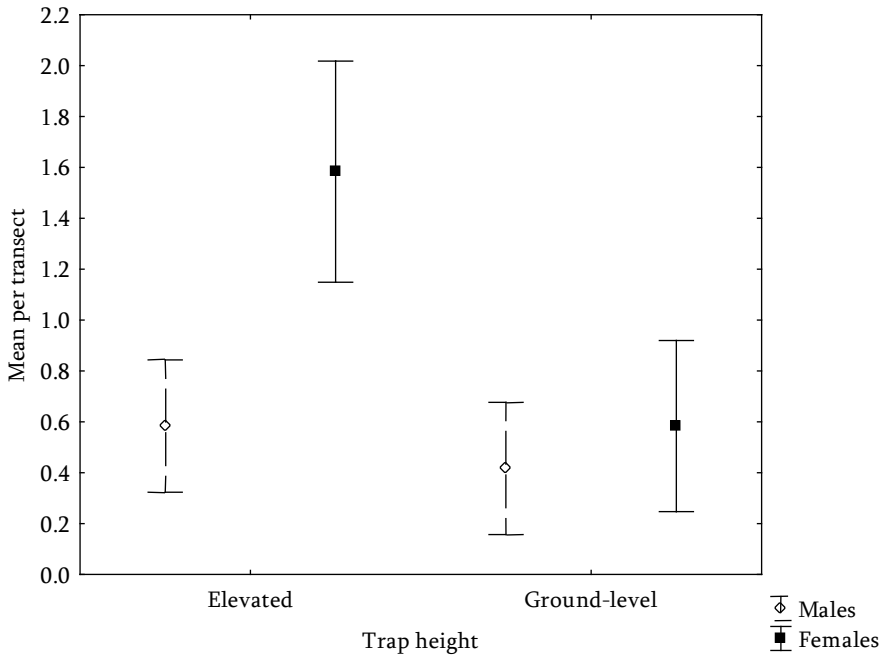

Figure 4.16 The relationship between harvest mouse sex and the height at which they were trapped in *Phalaris* between the months of September 2009 and January 2010. Figures shown are means per transect ±1SE.

4.3.9 Crop characteristics and harvest mouse abundance

A generalised linear model (GLM) was used to assess the effect of different crop characteristics on harvest mouse abundance. Crop type (*Phalaris*), crop height and the percentage cover of non-crop grasses were shown to be significant predictors of harvest mouse abundance (Table 4.14).

Table 4.14 Results from a generalized linear model (GLM) describing variation in harvest mouse abundance in the biomass crops taking into account various crop characteristics, using a log link function for a Poisson distribution.

	df	Estimate	SE	Wald statistic	P- value
Intercept	1	-1.398	3.241	0.186	0.667
Crop height	1	0.017	0.006	8.636	0.003
Crop % cover	1	-0.003	0.037	0.008	0.929
Crop type (*Phalaris*)	1	3.212	0.446	51.977	<0.0001
Litter	1	0.039	0.038	1.070	0.301
Bare ground	1	0.010	0.036	0.075	0.785
Non-crop grasses	1	0.046	0.009	25.697	<0.0001

4.3.10 Barn owl pellets

The 79 pellets and pellet-debris contained the remains eight species of small mammal (<50 g), as well as rat *Rattus* spp., chiropteran and avian remains, with field voles dominating the prey items (Table 4.15).

Table 4.15 Prey items found in barn owl pellets from two roost sites within 1 km of the biomass crop field.

Type of prey	Percentage of total items
Field vole	33.5
Wood mouse	16
Common shrew	13
Bank vole	6.3
Water shrew	6.0
Pygmy shrew	3.9
Harvest mouse	2.1
Unknown bird	0.5
House mouse	0.2
Rat	0.2
Unknown bat	0.1

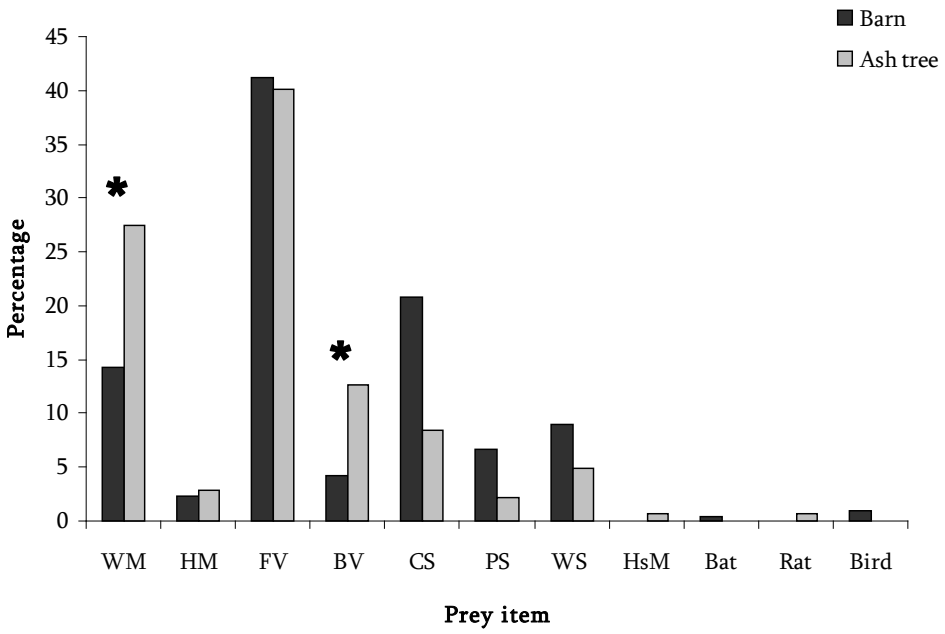

Figure 4.17 Proportions of the different prey items at the two different barn owl roosts. Asterisks show significant differences between the roost sites.

Both wood mice and bank voles were found in higher proportions at the ash tree roost than the barn (Kruskal-Wallis H (1, N = 79) = 13.631, $P < 0.001$ and Kruskal-Wallis H (1, N = 79) = 7.072, $P = 0.008$ respectively) as shown in Figure 4.17.

There were also differences between the proportions of the seven small mammal species trapped in the crop field and found in the owl pellets (Figure 4.18). Both wood mice and bank voles accounted for a higher proportion of captures from live-trapping than from pellet items, but for field voles the reverse was seen. All three shrew species appeared in the pellets in higher proportions than they were captured in the crop fields.

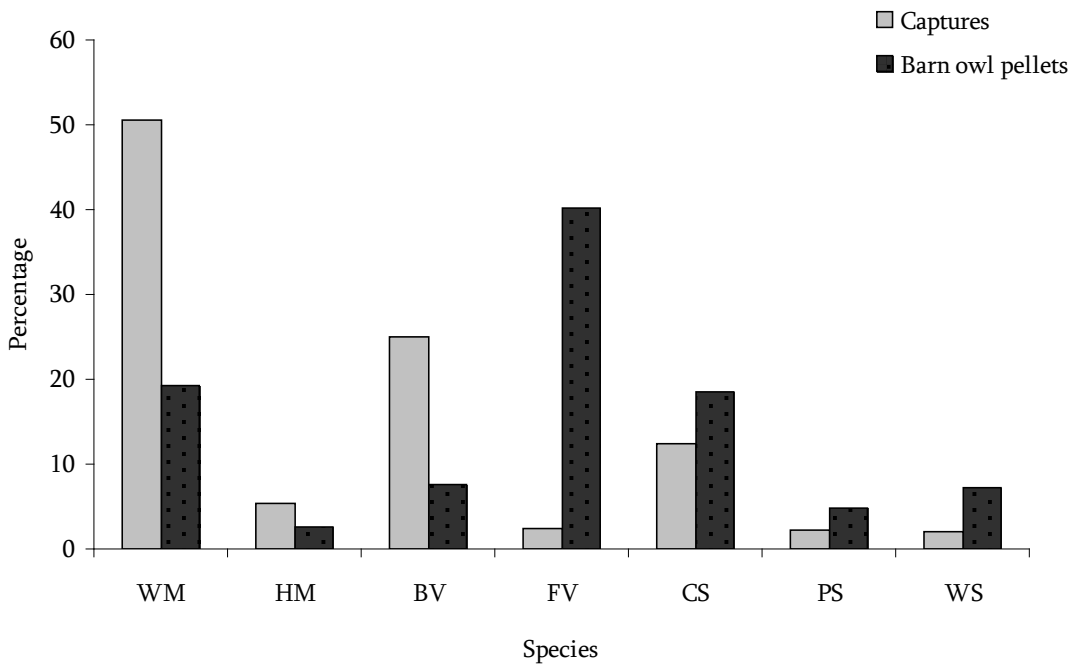

Figure 4.18 Comparison between the proportions of the different species caught in the biomass crop field over 1 year and those found as prey items in barn owl pellets (time range unknown).

4.4 Discussion

4.4.1 Presence of harvest mice and nests within the crops

Most harvest mice were trapped in *Phalaris*, with far fewer trapped per unit effort in *Miscanthus* and none in the hedgerows. Harvest mouse and breeding nest presence in the *Phalaris* was not entirely unexpected, as it has previously been reported as one of the favoured monocotyledons used for nest-building (Harris 1979a). The absence of trapped individuals in the hedgerows during the survey year was unexpected, as several harvest mouse nests were present in the hedgerows. Previous studies have widely reported breeding nests in hedgerow vegetation, particularly in bramble, hawthorn, blackthorn and cocksfoot (Bence *et al.* 2003; Harris 1979a). Where nests were found in the hedgerows around the biomass crops in the present study, they were constructed in these types of vegetation, which were in abundance. This may be due to some kind of seasonal change in habitat use occurring; for example if the hedgerows were suitable habitat early in the breeding season, but the biomass crop habitat became more attractive later in the year.

Despite harvest mice being trapped in low numbers in the *Miscanthus*, no nests were found there. Harvest mice native to Japan regularly breed in *Miscanthus* spp. (Hata 2011; Hata *et al.* 2010; Kuroe *et al.* 2007) so it is possible that breeding nests were present in the *Miscanthus* crop, but not as easily detected as those in the *Phalaris*. This may have been as a result of the mass of fallen leaves filling the space in between the stems near the ground and thus obscuring any nests present. Harvest mouse nests have been found in *Miscanthus* in Staffordshire (Derek Crawley, personal communication, Figure 4.19), so it is evident that they do at least occasionally breed in *Miscanthus* in Great Britain.

Figure 4.19 Harvest mouse above-ground nests in *Phalaris* (left; photo by Jenny Clapham) and *Miscanthus* (right; photo by Derek Crawley, Staffordshire Mammal Group).

Another possibility is that, given a choice between *Miscanthus* and *Phalaris*, the female harvest mice preferred the stem structure of the *Phalaris* for nest-building and therefore used that in preference to the *Miscanthus*. This possibility is supported by the finding that females were caught less frequently in the *Miscanthus* than *Phalaris*. Within *Phragmites* reedbeds, which are structurally similar to *Miscanthus*, nest building is less common where the stem structure is tall and thick with abundant herbaceous vegetation compared with sparser reed stems and abundant grasses and sedges (Surmacki *et al.* 2005).

No harvest mice were trapped in either the barley or maize crops. Harris (1979a) reported harvest mouse presence in most types of arable crop including barley, but not in maize. No other references can be found relating to harvest mice in maize, although Harris (1979a) cites unpublished work by Saint-Giron that showed a positive correlation between harvest mouse presence in barn owl pellets and the quantity of maize grown in the area.

There was no bias in the sex ratio of harvest mice captured across the whole site. This is in agreement with work performed throughout the year by Trout (1978a), although he did find that male numbers were lower in the middle of winter.

Assuming that the *Phalaris* is the preferred crop, the higher numbers of male harvest mice caught in the *Miscanthus* could be related to their larger home range size of 400 m^2 compared with 350 m^2 for females (Trout 1978b). Within the biomass crops, movement of recaptured individuals was not extensive (mean of 12 m), which was in agreement with Harris (1979b) who reported that most harvest mouse movement was restricted to a straight-line distance of less than 15 m. Durrer *et al.* (2006) attached radio-transmitters to captive-bred harvest mice which were then released into marshland habitat. Their positions were tracked hourly for 12 hours, with males moving a mean of 39 m and females 19 m. Their results should be viewed with caution however, as movements of previously captive mice in a foreign environment may not be true of wild mice. However, longer distances may have been travelled through or between the biomass crops, but these would only have been detected if the individuals involved had been recaptured.

Miscanthus contains a higher abundance of small mammals (of most of the taxa present locally) than *Phalaris* (Chapter 3), suggesting that there are good food resources within the *Miscanthus* crop. This may result in it predominantly being used by harvest mice for foraging and that breeding activities are restricted to the *Phalaris*. The high number of other small mammals within the *Miscanthus* may create interspecific competition that may also be a factor in how harvest mice are distributed. 75% of small mammal captures within *Miscanthus* were wood mice, in comparison with 4% harvest mice, whereas wood mice only comprised 41% of captures in the *Phalaris* crops compared with 30% harvest mice. Riordan *et al.* (2007) suggest that within a three-dimensional arboreal habitat populated by both harvest mice and wood mice, wood mice should be competitively superior due to a combination of biometrics and life history traits, and in the current study, increasing numbers of wood mice correlated negatively with harvest mouse numbers in the biomass crops. Competition from bank voles is likely to be less intense due to their predominantly ground-dwelling existence: where food is

widespread and abundant, bank voles actively avoid harvest mice (Ylönen 1990). The only time the bank voles were found to be competitively superior was when food supplies were limited.

Compared with other estimates of harvest mouse populations, site 'N' contains a low ratio of wood mice to harvest mice: 10:1 (in all areas surveyed throughout the year); 5:1 (biomass crops only throughout the year); 3:1 (biomass crops only during the months in which harvest mice were caught). These ratios are low in comparison with the mean ratio of 27:1 from the meta-analysis by Harris (1995) or the mean of 34:1 calculated from further papers (reported in Table 4.3). This low ratio appears to be site- and habitat-specific as reported ratios vary widely. For example, Moore *et al*. (2003) recorded ratios of 1:1 in new woodland plantations and 9:1 on farmland. Within all habitats surveyed in this study for the duration of the year-long trapping regime, harvest mice comprised 5.3% of all small mammals caught and this is similar to the 5.8% reported by Durrer *et al*. (2006) in a marshland habitat of *Phragmites* spp. and *Phalaris*.

4.4.2 Distance into crop

Moore *et al*. (2003) reported that harvest mice on arable land were only associated with linear features, suggesting that there could be an edge effect in the crops. This was not the case in either biomass crop as harvest mice were distributed throughout. There did appear to be a slight tendency for more harvest mice to be trapped in the transects 20 m from the crop edge, but this was not a significant trend. After harvest of the biomass, it is possible that the harvest mice retreat to the field margins until such a time as the biomass crop provides suitable habitat once more. In that instance, as the crop is re-colonised there may be a higher concentration nearer to the margins, but as no harvest mice were captured at that time, that mechanism remains unknown. This therefore suggests that in biomass

grass crops, linear features such as hedges may be of lesser importance than in other agricultural habitats.

4.4.3 Activity throughout the day

The majority of harvest mice were captured overnight (and found in the morning trap check), with far fewer caught in the middle of the day or in the evening. This agrees with previous studies on captive harvest mice, which showed activity during every hour of the day, but with peaks at dusk and dawn, regardless of day length (Trout 1978b). The morning check also represented the longest time since the previous check, and the longer period without disturbance may have added to the increased morning catch. In terms of catch per hour, no difference between times of trap checks were apparent.

Seasonal differences in daily activity levels were reported by Trout (1978b) who found that wild harvest mice followed a predominantly nocturnal existence in summer and autumn, changing to a diurnal pattern in winter. Although harvest mice in the biomass crops also showed increased diurnal activity in winter, this was not significantly different from the autumn or spring. Durrer *et al.* (2006) reported no bias in the time of capture between morning and evening for the eight harvest mice they caught in autumn.

No significant time differences were demonstrated between the sexes and this therefore suggests that daily activity patterns are similar in both sexes.

4.4.4 Recaptures

Detection of recaptured individuals depends on the persistence of the marking method. Fur clipping is considered to be a non-traumatic marking technique where the pigment-rich ends of the guard hairs are removed with scissors, exposing the grey under-fur (Putman 1995; Gurnell & Flowerdew 1982). It is now the

preferred method to more invasive techniques that were previously used. These included mutilation-based methods such as toe-clipping (Taber 1956); or the ringing of a hind leg (Chitty 1937), which often led to loss of circulation and the need to amputate (Evans 1942). In small mammals with larger ears, numbered ear tags have been used, although these can be lost through grooming, infection or through general wear (Taber 1956). Fur clip marks are predicted to remain detectable for up to 3 – 6 months but this partly depends on how moult progresses and how quickly the hair re-grows (Gurnell & Flowerdew 2006; Howe & Lane 2004). In the biomass crops, the longest interval between first capture (September 2009) and last capture (January 2010) was 146 days, after which the fur clip was still easily visible. This indicates that within this period, all recaptured individuals would have been readily apparent.

No animals marked before harvest in spring 2009 were known to be recaptured in the autumn or winter. This may have been due to the fur marks having grown out during a summer moult, or otherwise because those caught in the autumn and winter were progeny of the summer breeding season. Only four animals were in juvenile pelage on first capture, but as moult into adult pelage starts when they are 30 days old and is usually complete by 45 days old (Trout 1978b), it is possible that those caught in adult pelage in the biomass crops during the autumn and early winter were still less than two months old. It has been estimated that in October, up to 16% of the harvest mice in a population were less than two months of age (Trout 1978a).

Of the eleven recaptured individuals, only three were caught more than twice. Males were no more likely to re-enter traps than females, although the "trap happy" HM1013, captured seven times in total was male. Published data on other harvest mouse recaptures are sparse, although Riordan *et al.* (2007) recaptured two of the total of eight harvest mice trapped in autumn/winter. Of these two

individuals, one was caught twice and one three times. There was movement of harvest mice between the two crops, although apart from one recapture, all these were along a transect line at the same distance from the crop edge. For those recaptured within the same crop transect, most were found at a different trap position from their first capture, although distance moved was mostly around five metres.

Capture/mark/recapture methods are well established for tracking movements of individual animals, but the use of live traps can itself limit the daily movements of individual animals (Szacki 1999). Use of live trapping generally also only shows presence or absence in certain areas, rather than specific movements or amount of time spent in habitats.

In larger mammals, radio telemetry is frequently used to provide this kind of data, but it is only recently that radio-transmitters small enough and light enough to be used on harvest mice have been produced. Durrer *et al.* (2006) glued radio-transmitters to captive-bred harvest mice which were then released into a marshland. They were able to successfully track the mice until the transmitters fell off, between 56 and 64 hours after attachment. A further study (Buss *et al.* 2009) trialled two designs of radio-transmitter on captive-bred harvest mice: a collar formed by a cable-tie, and a backpack version glued to the dorsal fur. Both versions weighed no more than 5% of the animal's weight, which is considered to be the maximum weight that can be applied without negatively impacting the animal. Grooming behaviour intensified in the first few hours after attachment, leading the authors to advise keeping wild animals captive for at least four hours after attachment of the device, in order to reduce the increased predation risk associated with the grooming and consequent distraction caused by the foreign object. Most of the backpacks were lost within 10 days and this was attributed to the type of glue used. Food consumption and body weight were measured for the duration that the

device was worn, with no negative effects being seen for the collar device in terms of weight loss or increased dietary intake, in comparison with harvest mice that had been handled but not had a transmitter attached. The backpack group lost some weight, but this was thought to be skewed by the inclusion of heavier than normal individuals who simply reduced their weight to more normal limits. The authors concluded that once a sufficiently effective glue for the backpacks was found, that radio-telemetry using these devices would not cause any detriment to the mice (Buss *et al*. 2009).

The use of radio-telemetry could be a vital tool in the future for gaining insight into how harvest mice use and move within and use their habitats, and most especially to determine their movements once the biomass is harvested.

4.4.5 Body weight variations

Across the year of trapping in the biomass crops, mean weight of males (6.4 ±0.2 g, n = 36) was significantly higher than the females (6.0 ±0.1 g, n = 41). Riordan *et al*. (2007) also reported heavier males (mean 6.1 ±0.4 g, n = 6) than females (4.8 ±0.2 g, n = 2) in their much smaller sample. Mean weights were not significantly different for harvest mice caught in the different biomass grass crops, suggesting that they were able to exploit equivalent food resources in the two crops.

Mean weight of male harvest mice was significantly lower in the autumn (September, October and November) than in the winter or spring. In comparison with their maximum weight in winter, mean weight in the autumn was 33% lower. Harvest mice reach full adult weight by the time they moult into adult pelage at 45 days old (Harris 1979b) and as only four animals were considered to be in juvenile pelage when weighed, it is less likely that the lower autumn male weight can be accounted for by increased numbers of juvenile mice. Although females were also at their lowest weight in the autumn, the difference to their maximum weight

recorded in spring was a non-significant mass change of 8%. The weight difference between the autumn and spring was smaller in female harvest mice despite possible differences due to breeding and pregnancy (although no females were witnessed to be lactating at the time of weighing). The difference in male weight between autumn and winter is less likely to be related to available food resources than to changed behaviour in the breeding season that results in a loss of condition. Harvest mice are not considered to be sociable animals, with dominant members of the population often demonstrating aggressive behaviour to subordinates and juveniles (Harris 1979b). Trout (1978b) reports frequent aggression between captive males, but also comments that when breeding is not taking place, high densities of harvest mice co-exist amicably. During the breeding season, one or several males may pursue a female until she is receptive (Harris 1979b) and the time taken up by the pursuit of mates is likely to reduce the foraging time available to males, potentially leading to a reduction in body mass. Brandt & Macdonald (2011) reported that under laboratory conditions, female harvest mice in oestrous preferred heavier males and it is therefore clearly in the male harvest mouse's interest to maintain their weight during the breeding season.

Riordan *et al.* (2007) reported an opposite trend for combined mean weights of four species of rodent (harvest mouse, wood mouse, bank vole and field vole), where maximum weight was recorded in spring/summer, dropping further in autumn and the lowest weights recorded in winter. Work on the meadow vole *Microtus pennsylvanicus* also revealed loss of weight during the winter after a peak at the beginning of August, with weight only starting to increase in February (Iverson & Turner 1974). This was thought to be due not only to the reduction of available food, but also an influence of day-length cues. Jackson *et al.* (2001) live-trapped field voles between November and March for two years and recorded minimum mean body mass in January and the maximum in March. Korn (1989) suggests that

winter weight loss is related to the need to reduce energy requirements outside the breeding season during harsh winter weather, and is also triggered by photoperiod.

Where repeat trapping has been performed, declines in body mass have been reported for three North American small mammal species (Pearson *et al.* 2003). Mass loss was attributed to hypothermia and dehydration and the authors therefore warn against the use of overall small mammal biomass as a population index for this reason. However, mass loss in the male harvest mice in the biomass crops occurred before the onset of cold winter weather, and at a time where food resources should be at a peak, suggesting that these are the least likely causative factors. Although there is a potential risk of weight loss or dehydration occurring during the time that the harvest mice were in the traps, the provision of grain, mealworms and carrot should have ensured that this did not occur. No further explanations for seasonal body mass changes could be found in the literature.

4.4.6 Seasonal differences in captures

Other studies have reported an absence of harvest mouse captures in late spring and summer (Durrer *et al.* 2006; Trout 1978a). In the current study, the latest captures in spring coincided with the timing of harvest and no harvest mice were captured in other areas of the site once harvest was complete. This was despite the availability of adjacent woodland with a dense ground layer and also dense hedgerows around the site, both of which should provide suitable habitat. It is unknown whether captures may have continued beyond the end of March had a buffer strip of *Phalaris* or *Miscanthus* have been left as a refuge. Certainly one of the individuals captured in the *Miscanthus* crop before it was harvested had moved to the *Phalaris* crop, which stood intact for a further week after the *Miscanthus* was cut. Whether this movement occurred as a result of the harvesting process or prior to it happening is unknown. An assumption could be made that movement to other suitable habitat would be the norm for any harvest mouse surviving the

harvesting process and therefore that areas of crop left un-harvested as a refuge could be useful.

Without any post-harvest captures, it is impossible to know what the harvest-induced mortality rates would have been – either due to the mechanical process of harvesting or the resulting increased predation rates when the crop cover is removed (e.g. Tew & Macdonald 1993).

The first autumn capture of a harvest mouse on 4th September is considered to be earlier in the autumn than usual (Roger Trout – personal communication), as most harvest mice only start to enter traps again in October.

In the months that harvest mice were caught, no seasonal change in capture rates was seen in *Phalaris*. As the *Miscanthus* was harvested in February (winter), no capture data for spring (March, April, May) were available. Despite this, there were no differences between autumn and winter catches in *Miscanthus*. Winter 2009 / 2010 was particularly harsh, with temperatures in Pembrokeshire reaching minus 16°C, with prolonged snowfall for several weeks. The intended survey at the beginning of January had to be cancelled due to these weather conditions. By the end of January, conditions were suitable for trapping once more, but capture success appeared to be lower than expected based on the trend seen the previous winter. Whether this was entirely due to the climatic conditions is uncertain. A confounding factor existed, in that the landowner had taken advantage of the frosty weather and had already harvested *Miscanthus* 2, as well as one swathe of *Miscanthus* 1 before realizing that surveys had not yet ended. Whether this mechanical disturbance prompted harvest mouse movement out of the crops is unknown.

Despite this, on the final survey at the end of January, two key animals were captured: HM20036, a male which, at 7.3 g was the heaviest harvest mouse captured since February 2009, and also HM20001 - the first harvest mouse to be captured in autumn 2009. The heavy weight of HM20036 and the relative longevity of HM20001 suggest that the severity of the winter did not necessarily negatively affect harvest mouse survival. Abundance of other species captured at the same survey showed varying declines and increases from the previous survey in November 2009. Wood mice, harvest mice and bank voles were all captured in lower numbers in January 2010, but captures of all shrew species increased. This increase in shrew captures may have resulted from increased foraging activity and therefore an increased likelihood of them entering traps to find food. But it is striking that the shrews had survived well despite the cold temperatures and the shrews' very high metabolic rate, possibly by being able to exploit the insulated area of vegetation between the ground and snow. The harvest mice, with both their relatively high surface area: volume ratio of 4.9 (Trout 1978b) and their omnivorous diet, as well as a ground-based winter existence might therefore be expected to survive harsh conditions as well as the shrews.

Whether indeed the mechanical disturbance accounted for the reduced numbers of harvest mice rather than winter weather cannot be answered with the available data, but the availability of radio-telemetry to determine movements would have been useful.

It has generally been accepted that the seasonal pattern of harvest mouse population growth reaches its peak in November and is at its lowest in February and March (Haberl & Krystufek 2003; Harris 1979b; Trout 1978a). If that is the case, the high numbers of harvest mice caught in February and March in the biomass crops could represent a significantly larger population in the surrounding countryside than first thought.

4.4.7 Captures at different heights

It is known that harvest mice spend the summer in the stalk zone and are difficult to catch during this time (Trout 1978a). In order to increase chances of capture during the summer, from the time that the biomass crops were approximately 50 cm high and the cereal crops were >20 cm high, traps elevated 40 cm above ground level on tripods were alternated with traps set at ground level along the length of each transect. The height of 40 cm was chosen as it represents the most commonly recorded height of nests within beetle banks and field margins (Bence *et al.* 2003). Harvest mice were only caught in the elevated traps in *Phalaris*. This appeared to be a species-specific factor rather than a structural one, as many more wood mice were caught in the elevated traps in *Miscanthus* than in *Phalaris*. Riordan *et al.* (2007) also reported a high trapping success rate of 38% for wood mice in elevated traps, in contrast to the results of Nordvig *et al.* (2001) where wood mice were not trapped at all in elevated traps in field margins. The elevated traps in the *Miscanthus* were moved to ground level in November, as strong winds bent the *Miscanthus* stems so much that the tripods were knocked over causing the traps to fall to the ground.

Total numbers of harvest mice caught in elevated traps were over double those found at ground level. The attempt to trap harvest mice earlier in the summer using elevated traps was successful in that the first harvest mouse capture in early September was made in an elevated trap. However, by the beginning of October, ground-level captures were also being made, so any temporal advantage of using elevated traps seemed to be short-lived and did not show the same success as reported by Sibbald *et al.* (2006). Overall though, elevated traps resulted in more harvest mouse captures than those at ground level, suggesting that optimum trapping methodology should include traps at both heights.

There was a link between the sex of the harvest mouse and the height of the trap it was caught in, whereby females were more likely to be found in elevated traps. It is unclear, however, whether this resulted from the differing foraging behaviour of males and females. As most captures were made outside the breeding season, females were perhaps less likely to stay around aerial breeding nest sites than when actively breeding, so the reason for the higher numbers of females in elevated traps is unknown.

4.4.8 Crop characteristics

Neither the percentage of crop cover nor crop height were significant factors in determining harvest mouse presence, but the quantity of bare ground, litter and non-crop grasses were significant factors. This is in accordance with results found in reedbeds, where nest-building was more commonly associated with less dense stems and an abundance of grasses and sedges (Surmacki *et al.* 2005).

4.4.9 Barn owl pellets

Barn owls are known to have a hunting range of approximately 1 km from their nest site during the breeding season, extending to 4.5 km during the winter (Ramsden & Ramsden 2002). It is likely that the occupants of the two roosts would have the biomass crop field within their hunting range and this appeared to be confirmed by the sighting of a barn owl hunting in the field late one evening. It is therefore assumed that the contents of the pellets would include small mammals from the biomass crop field as well as from the surrounding farmland.

Proportions of potential small mammal prey known to be present within the biomass field (i.e. those caught in the live traps) and those actually consumed by the barn owls had a different composition. This indicates a degree of prey selection or differences between species of small mammals in their risk of capture by barn owls, which hunt preferred prey, not necessarily those that are the most

abundantly available (Love *et al*. 2000). Although wood mice were the most abundant species in the traps in the current study, the field vole dominated in the pellets, as also reported by Love *et al*. (2000). One has to use some caution, however, when considering these results: (a) because although it is likely that the pellets contained prey from the crop field, it would not have been the sole hunting area; (b) the trapping data covered a whole year, but some of the pellets may have been older than that and therefore could have represented cyclic prey abundance not detected by the trapping, and (c) any statistical analysis beyond the calculation of percentages was not possible.

Harvest mice comprised 2.1% of all prey items in the pellets, which is in agreement with other work on barn owl pellets (Sibbald *et al.* 2006; Love *et al.* 2000) and domestic cat prey (Woods *et al*. 2003). As 5% of the total small mammals trapped over the course of a year at the biomass site were harvest mice, one can infer that they are only a minor prey item for the barn owl and are hunted in proportion with their abundance. Had it been possible to collect pellets monthly for the whole year, it may have been possible to match barn owl prey with live-captures on a seasonal basis. However, there is evidence to suspect that the two are related, since Trout (1978a) reported an absence of harvest mouse remains in barn owl pellets that coincided with the time during which they were not found in traps over the summer.

Barn owls most commonly hunt in rough grassland (Askew *et al.* 2007) and are able to catch prey at some depth into the vegetation. A factor to consider in the biomass grass crops is the ease of access for hunting barn owls in relation to the architecture of the crops. Small mammals in *Phalaris* may be accessible to them, but both the dense stems and height of the *Miscanthus* may prevent them from hunting effectively within it.

4.4.10 Context within Wales

Harris (1979a) reported only 36 harvest mouse records for Wales between 1973 and 1977, of which nest sightings were predominant. In Pembrokeshire only 9 harvest mouse records had been reported before this study was undertaken (Figure 4.20), although this was possibly due to lack of intensive surveys in the area rather than there only being a small population present. A large, dense, mature reedbed is present on the banks of the Eastern Cleddau river, within a kilometre of the biomass grass crops. It is possible that the population of harvest mice utilised this as habitat at some stage prior to the biomass crops being planted. At the time of this study, the reedbed was searched for the presence of harvest mice, but no nests were found. Useful future work would include more detailed surveys of the general area, in order to establish whether the biomass crop field harvest mice are a unique population, or one of many previously unrecorded populations in the general area.

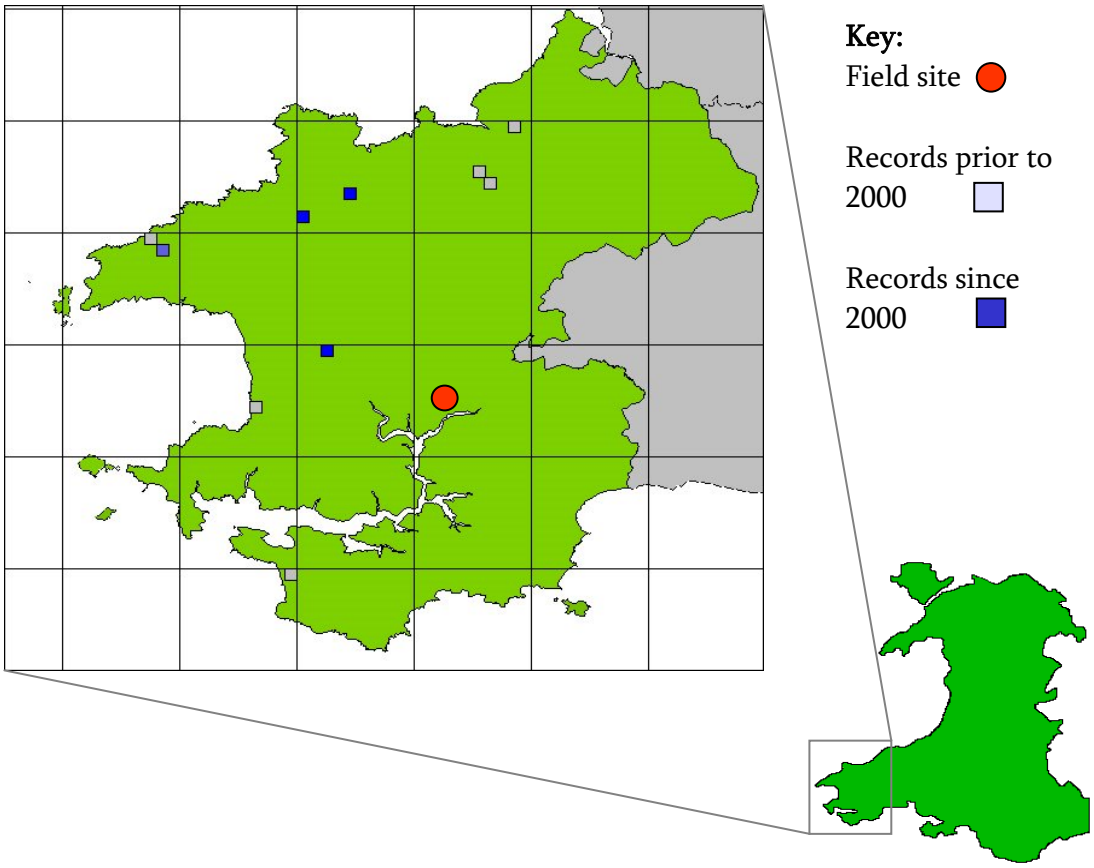

Figure 4.20 Map of Pembrokeshire showing previous harvest mouse records in relation to the biomass crop site (Courtesy of A. Haycock, County Mammal Recorder).

4.4.11 Conclusions

In conclusion: concern has been expressed in some quarters about possible negative effects of biomass grass crops on native faunal biodiversity (Groom *et al.* 2008). Results from this study indicate that the biomass grass crops, particularly *Phalaris* provide excellent habitat, supporting a minimum of 58 harvest mice in one hectare over one year at the site in Pembrokeshire. In this study, harvest mice were trapped in both crops, but not in the surrounding hedgerows or cereal crops. Recaptured individuals were often captured at different locations, indicating that movement around and between the crops occurred. Harvest mice were only trapped between the months of September and March, suggesting that small mammal surveys outside these times may not adequately describe harvest mouse presence. Breeding nests were evident in the *Phalaris* and the surrounding hedgerows, and the capture of individuals in juvenile pelage showed that breeding was occurring. Biometric data showed seasonal fluctuations in male harvest mouse body weight that has not been previously reported. Although males and females were captured overall in equivalent numbers, harvest mice caught in *Miscanthus* were more likely to be males.

If comparisons are to be made between *Miscanthus* and *Phalaris*, then the *Phalaris* is undoubtedly a superior habitat for harvest mice and could be considered as a possible 'conservation crop' in areas where efforts are being made to restore or increase harvest mouse populations.

If Bence *et al.* (2003) are correct in their assumption that the harvest mouse is a good indicator of habitat quality and faunal diversity in general, the results reported here for harvest mice suggest that fears relating to the introduction of perennial biomass grass crops are unfounded.

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CHAPTER 5

BIOMASS GRASS CROPS AS HABITAT FOR BIRDS ON AGRICULTURAL LAND

Abstract

Plantations of the biomass grasses *Miscanthus* x *giganteus* and *Phalaris arundinacea* could become widespread on UK agricultural land as part of a move to produce more low carbon energy. Fears have been expressed regarding the potential impact of these plantations on bird species using farmland, in particular those species which are farmland habitat specialists. Between April 2008 and January 2010, surveys by means of walking transects and mist netting were carried out bi-monthly at four biomass grass crop sites and adjacent comparison sites across mid- and west-Wales and Herefordshire in order to determine bird species presence within the biomass crops and the comparison sites. Birds caught in mist nets were ringed and biometric measurements were taken.

A combination of mist netting and walking surveys revealed more bird species than would have been detected using only one survey technique. *Miscanthus* contained a more abundant and diverse bird assemblage than the *Phalaris*. There were no differences in the abundance of either males and females, or juveniles and adults within the biomass crops. The predominant component of the diet of birds in the biomass crops was invertebrates rather than seeds, and no significant differences were seen between birds caught in the two biomass crops in terms of body condition. More red-listed bird species were found in the comparison sites than the biomass crops, and the biomass crops contained more birds typical of woodland than farmland habitat. More farmland habitat-associated bird species were found in the comparison plots. The biomass crops contained several summer migrants, mainly warblers that were not found in the comparison plots.

5.1 Introduction

5.1.1 Farmland bird declines and agricultural intensification

Land used for agriculture (pasture and arable land) and horticulture, together accounted for 58% of land use in Wales and 68% in England in 2007 (NERC 2009; Smart *et al.* 2009). These "farmland" habitats therefore represent a very large and important habitat for birds. Farmland habitat varies widely, from upland moors through to grasslands, cereal, fruit and vegetable crops. In addition to land in primary agricultural production, farmland often also incorporates areas of woodland and hedgerows. This mosaic of habitats provides opportunities for many different bird species, many of them farmland specialists.

In recent years, concern has been raised over rates of decline in some farmland bird species. Between 1990 and 2000, European farmland bird populations showed a significant decline, unmatched in any other habitat assemblage and linked to agricultural intensification (Donald *et al.* 2006). Different studies cover various time-spans, from the 1960s to the present day, but all are in agreement that certain farmland species are in significant decline (e.g. Donald *et al.* 2006; Henderson *et al.* 2004; Taylor & Grant 2004; Chamberlain & Fuller 2001; Fuller *et al.* 1995). Declines of 86% (24 of 28 species) in the distribution of farmland birds were reported between 1970 and 1990 (Fuller *et al.* 1995) and a 44% reduction in farmland birds on the Index of Population of Wild Birds from 1970 to 2005 was reported by DEFRA (2006). These rates of decline exceed those of birds in other habitats, such as woodland birds. Possible reasons for the rapid declines among farmland birds vary between species and are related to different pressures related to habitat, predation pressures and climate (Fuller *et al.* 1995), although modern farming techniques are widely linked to farmland bird declines (Grice *et al.* 2004). Summer migrants face additional pressures at their overwintering grounds, as was seen in the whitethroat *Sylvia communis*, which suffered a population crash in 1968 – 1969 due to a drought in its African winter range (Fuller *et al.* 1995).

Current global trends in land-use changes, agricultural intensification and increasing usage of agrochemicals have been predicted to lead to a loss of up to 18% of the world's avifauna (15.3 billion birds) by 2050 (Teyssedre & Couvet 2007). These predictions are based on agricultural expansion alone and do not include other threats to bird populations such as over-harvesting, climate change or biological invasions. Within Europe, range contractions and population declines in farmland birds were found to be greater in capitalist countries where agricultural intensification was well-established in comparison with former communist countries with less intensification of agriculture over the 20th Century. Indeed, more than 30% of variance in bird population changes could be explained by cereal yield alone (Teyssedre & Couvet 2007). Although the general trend for most farmland bird species has been one of reduced populations, conversely, a small number of species have actually increased in number in association with agricultural changes. Examples of this include the whitethroat and chaffinch *Fringilla coelebs*, which showed an increase in numbers between 1970 and 1990 (Chamberlain & Fuller 2001). This may reflect the level of specialism demonstrated by individual species in terms of reliance upon farmland habitat for breeding and foraging: generalist farmland birds increased by 4% between 1970 and 2002, whereas farmland specialists declined by 58% over the same period (Gregory *et al.* 2004).

Agricultural intensification has led to changes in both grassland and arable crop structure. Grass swards have become more dense and homogenous, resulting in loss of botanical and faunal diversity (Wilson *et al.* 2005). Crop structure influences bird presence in several ways: through concealing predators (or the birds from them), protection or exposure to the prevailing weather and the abundance of food (Wilson *et al.* 2005). Skylark *Alauda arvensis* were seen to favour tractor-wheel tram-lines in cereal crops for foraging, despite a lower abundance of prey items

within them. This may have been influenced by a trade-off between the need for vigilance and food accessibility (Wilson *et al*. 2005).

For some non-passerine bird species, breeding failure is thought to be a more significant contributor to their decline than failure to survive as adults (Gregory *et al*. 2004). Ground-nesting birds are particularly sensitive to production intensity, which can lead to increased disturbance, either from higher stocking rates of livestock or increased machinery use. Bas *et al*. (2009) report that 68% of ground-nesting species responded negatively to farming intensity, compared with only 21% of hedge-nesters, despite the loss of hedgerows during the intensification process. This further illustrates the complexities of the effects of intensification on bird species with different habitat requirements.

5.1.2 Grassland birds

The wide array of habitat requirements of different bird species means that effects of agricultural intensification can also vary across spatial scales. Gates & Donald (2000) examined local extinctions of farmland bird species, and found that although habitat requirements differ between species, an area suitable for one species was also likely to be suitable for other species. Areas abandoned by birds had become intrinsically unsuitable compared with other areas in which the species persisted.

Both Gates & Donald (2000) and Chamberlain & Fuller (2001) reported reduced bird populations in grassland-dominated areas, predominantly in western parts of Britain. In marginal upland, grassland-associated species such as the skylark, wheatear *Oenanthe oenanthe*, whinchat *Saxicola rubetra*, yellow wagtail *Motacilla flava* and yellowhammer *Emberiza citrinella* declined by 80% between 1968 and 1980 (Henderson *et al*. 2004). Reasons for declines in grassland birds cannot be generalised, but it is thought that reseeding with competitive grass species and increased use of fertilizer and pesticides are contributory factors (Fuller *et al*. 1995).

Such changes reduce botanical and invertebrate diversity and result in lower food availability. A change from hay meadows with a single cut in late summer to grass cut for silage multiple times over the summer, as well as higher stocking levels on lowland grazed fields may also influence breeding success for ground-nesting birds, resulting from reduced sward height and an increase in trampling (Fuller *et al.* 1995). Intensity of grazing can be of importance to grassland birds, as the height of sward at which a bird prefers to forage will determine how susceptible it is to grazing (Martin & Possingham 2005).

In general, modern intensive grassland systems are not as favourable habitats for some farmland birds as mixed or arable systems (Chamberlain & Fuller 2001). In Alpine meadows, fledging success of the whinchat was greater in traditionally managed meadows than those under more intensive management. In the intensive meadows, invertebrate density was lower and foraging distances were greater, which resulted in a reduced invertebrate biomass being fed to the chicks (Britschgi *et al*. 2006). A study comparing varying intensities of grassland management with fallow land revealed the highest numbers of medium-sized arthropods in grazed pastures and extensively used (two – three cuts of grass taken per year) meadows (Zahn *et al*. 2010). Fallow land had similar numbers of arthropods as the extensive meadows and pasture, all of which contained greater quantities than were found in intensively used (cut more than three times per year) meadows. Two or more cuts of grass per year resulted in reduced arthropod diversity (Zahn *et al*. 2010). However, increased use of nitrogen fertilizer and shorter swards resulting from increased grazing pressure have been shown to have a positive impact on the starling *Sturnus vulgaris*, blackbird *Turdus merula*, pied wagtail *Motacilla alba*, dunnock *Prunella modularis* and corvids, through improved access to soil invertebrates (Atkinson *et al*. 2004). Measures to improve foraging habitat for birds include scarification of grassland sward in order to produce a mosaic of bare ground patches can benefit both ground invertebrate and seed feeders, but the

effect may be short-lived (Schaub *et al.* 2010; Whittingham *et al.* 2006; Perkins *et al.* 2000).

Buckingham *et al.* (2006) found that sward structure was more important to foraging birds than the types of plants within the sward. Tall swards are associated with higher invertebrate abundance and diversity in comparison with shorter swards (Atkinson *et al.* 2004) and may also be preferred by granivorous birds (Buckingham *et al.* 2006). Where longer swards are exploited, there is a risk of the bird becoming wet and chilled if the vegetation is wet, and this may be a significant factor when making foraging decisions (Wilson *et al.* 2005; Perkins *et al.* 2000). Increased risk of predation in taller swards (as a result of obstructed view of potential predators), as well as increased difficulty in accessing prey items amongst dense vegetation may influence the preference for foraging in shorter swards and bare ground seen by soil invertebrate feeders (Buckingham *et al.* 2006; Atkinson *et al.* 2004).

Pärt & Söderström (1999) also reported on the relative importance of sward structure and plant species composition in relation to bird diversity. Only a very weak relationship was seen between vascular plant diversity and bird diversity, suggesting that use of botanical species richness as an overall indicator of general biodiversity was unreliable. Plant community composition relies heavily on local abiotic factors, whereas birds are able to move more extensively around a habitat and their diversity is more likely to be influenced on a landscape scale (Pärt & Söderström 1999). Nevertheless, plant diversity may itself influence bird abundance and distribution: either generalised herbicide applications or more locally utilised spot control of individual weed plants can result in reduced numbers of foraging granivorous birds (Buckingham *et al.* 2006).

Much of the agricultural landscape of northern and western Britain contains marginal upland pasture. In these areas between 1968 and 1980, there was an 80% reduction in numbers of skylark, wheatear, whinchat, yellow wagtail and yellowhammer. Several species were also only found in 50% of plots in which they were originally found at the beginning of that period and the declining species were predominantly those which required grassland for nesting or foraging (Henderson *et al.* 2004).

5.1.3 Changed arable crop rotations

A change from spring-sown cereal crops to those drilled in autumn as part of agricultural intensification is thought to have had a negative impact on farmland bird populations, through both the absence of winter stubbles and springtime ploughing (Fuller *et al*. 1995). Winter stubbles provide spilt grain and seeds of annual weeds that are important resources for granivorous bird species. Springtime ploughing provides access to invertebrate food resources that are vital to insectivorous birds prior to the breeding season (Fuller *et al.* 1995). For ground-nesting species such as the skylark, crop height was highly significant to their breeding success, with lower occupancy rates in swards of over 30 cm height (Chamberlain *et al*. 1999). Autumn-sown crops were taller earlier in the breeding season, resulting in fewer breeding attempts than those made in spring-sown cereals, where the breeding season was longer (Gregory *et al*. 2004; Siriwardena *et al*. 2001). Although Siriwardena *et al*. (2001) reported positive associations between acreage sown with spring barley and the breeding success of the bullfinch *Pyrrhula pyrrhula*, tree sparrow *Passer montanus* and yellowhammer, a general reduction in bird breeding performance was associated with areas where intensive agriculture was practised.

5.1.4 Mixed farming as an alternative to arable or pastoral

Prior to the advent of mechanisation, horse powered farming methods dominated and mixed farming was more common due to the need for the working horses to be fed cereals in addition to grazing. The requirement for mixed farming was reduced when mechanisation negated the need for horses to work the land, although in some areas it is still practised. Mechanisation also led to larger-scale operations and more intensive agriculture, particularly when agro-chemicals became available (Robinson *et al*. 2001). Homogenisation of the landscape, through focusing on one type of crop, is likely to lead to a reduction in biodiversity and so the conservation of biodiversity requires the maintenance of a diversity of vegetation and habitat types on all forms of agricultural land (Martin & Possingham 2005; Woodhouse *et al*. 2005).

The complexities of habitat requirements by different farmland specialists can hamper attempts to devise strategies for optimum agricultural management for birds. An increase in the area of arable land within a pastoral landscape benefited grey partridge *Perdix perdix*, skylark, tree sparrow, corn bunting *Emberiza calandra*, reed bunting *Emberiza schoeniclus*, yellowhammer and whitethroat, but had a negative impact on house sparrow *Passer domesticus*, dunnock, robin *Erithacus rubecula*, blackcap *Sylvia atricapilla* and four finch species (Robinson *et al*. 2001). Siriwardena *et al*. (2001) also reported positive impacts on breeding success for the yellowhammer where the area of arable land increased, but the opposite for skylark and reed bunting. Although it is thought that feeding and nesting opportunities should be more numerous where mixed farmland is present, Siriwardena *et al*. (2001) could not identify any positive benefits at the level of breeding success for individual pairs of birds, although they thought that at community level, there may be benefits in terms of abundance and diversity.

5.1.5 Impacts of agri-environment schemes and set-aside land

Agri-environment schemes were introduced in the 1980s in order to benefit biodiversity through the adoption of more 'environmentally friendly' practices in return for additional financial subsidies paid to farmers by the European Union. In addition to this, a further 'set-aside' scheme was established around the same time, intended to reduce the overproduction of cereals. It prescribed that a certain proportion of land (up to 10%) be taken out of arable production for a minimum of one year and this proved to have additional benefits for wildlife (Macdonald *et al.* 2007). More detail on this scheme is given in section 3.1.6. Compulsory use of land as set-aside was curtailed in 2008, although some areas of set-aside land still exist as part of agri-environment schemes (DEFRA 2009).

While the compulsory set-aside scheme was in existence, the land included in the scheme was associated with increased density and diversity of bird species in comparison with grass or tillage (Gillings *et al.* 2010; Bracken & Bolger 2006). Since the abandonment of the set-aside scheme, it is estimated that between 25% and 50% of farmland birds will be affected by the loss of set-aside habitat, resulting in the need for them to relocate to other winter habitats, a factor which could increase the rate of decline in species such as the yellowhammer and skylark (Gillings *et al.* 2010).

Agri-environment schemes available to farmers have evolved since they were first introduced, and the available options also vary between the different countries of the UK. Management options may benefit different taxa in different ways. For example, the yellowhammer has an ideal nesting habitat of grassy margins and hedges bordered by vegetated ditches (Bradbury *et al.* 2000), but options to create optimal foraging areas for birds include a floristically diverse field margin rather than one comprised only of grasses (Vickery *et al.* 2009). It is clear that no one field margin option is suitable for all species at all times of year and this suggests that a

mosaic of management options of margins, boundaries and hedgerows is best for maintaining biodiversity at a landscape scale (Vickery *et al*. 2009). It has also been suggested that agri-environment options based on a regional or local scale may be more likely to benefit farmland birds rather than on a national scale due to the variation in habitat requirements of different avian taxa in different parts of the country (Gottschalk *et al*. 2010; Whittingham *et al*. 2007). There is some question, however, of the efficacy of agri-environment schemes in conserving declining bird populations in Europe, but this is thought to be due to the fact that few schemes specifically target birds (Donald *et al*. 2006).

A lead-in period also needs to be considered in establishing agri-environment options. In England, the Arable Stewardship Scheme showed little benefit to farmland birds in the first two years. However, the longer grass leys were left untilled, the higher the number of invertebrates present and the more suitable the leys as foraging habitat for species such as the starling (Bradbury & Allen 2003) – an effect that would not have been apparent in the early stages after establishment.

The major effects of pesticides are discussed below, but organic farming is often purported to be more environmentally aware and can lead to higher abundance of species such as the lapwing *Vanellus vanellus*. However, the absence of agro-chemical use in organic farming systems may result in an increased requirement for mechanisation and disturbance in order to control weeds and this could negatively influence nest success for lapwing and other ground-nesters (Kragten & Snoo 2007).

5.1.6 Impacts of pesticides

Pesticides (specifically herbicides and insecticides) may either have a direct effect on farmland birds, by reducing the availability of invertebrate food or weed seeds, or an indirect effect, where herbicides reduce numbers of weed-associated invertebrates (Boatman *et al*. 2004). The indirect effect of herbicides is made more

complex by the fact that not only does weed control reduce the number of phytophagous invertebrates, but also affects other invertebrates by removing refuges and changing the microclimate within the crop (Moreby & Southway 1999). In general, agricultural intensification is linked to a reduced abundance of invertebrates, which in turn has impacted on bird populations (Benton *et al.* 2002).

Corn buntings changed their foraging patterns in response to herbicide use, favouring crop areas in which applications were the lowest (Brickle *et al.* (2000). The authors also examined availability of small invertebrates suitable as chick-food items and found these to be negatively related to pesticide applications. In studies on the effects of pesticide use on the yellowhammer a significant relationship was seen between application rates and chick food, as well as nestling condition, growth rate and ultimate survival (Boatman *et al.* 2004). The condition of nestlings at day 6 after hatching was positively correlated with the availability of invertebrates suitable as chick food (Hart *et al.* 2006). Early broods were particularly affected by the reduced availability of chick food due to insecticide applications, whereas the diet of broods hatched later in the season was supplemented with unripe grain (Morris *et al.* 2005) and therefore less susceptible to low invertebrate availability. Effects of insecticide on bird mortality were not just restricted to the chicks: adults in areas of low invertebrate density were thought to compromise their own survival by allocating more time and energy to feeding their chicks (Boatman *et al.* 2004).

Ways of mitigating the effects of pesticide use were examined by Holland *et al.* (1999). They found that the majority of arthropods within a crop field were within 60 m of the crop edge (a result of recolonisation from the field margins), and suggested that a 6 m buffer zone (in which pesticides were not sprayed) at the crop edge would facilitate movement of invertebrates back into the crop. Depletion of invertebrates in the middle of crop fields as a result of insecticide use negatively affect the skylark (Holland *et al.* 1999), as it has been noted that they tend to forage

well away from hedges at the field margin as an anti-predator strategy (Wilson *et al.* 2005).

5.1.7 Impacts of biomass grass crops

Until very recently, the potential effects of energy grass plantations on bird populations have been based on speculation, rather than empirical data, particularly as some of the grasses used are non-native. In an American Midwest scenario, it was thought that switchgrass *Panicum virgatum* biomass crops would create habitat for some grassland birds, but negatively impact others (Murray *et al.* 2003). In the UK, the tall and dense structure of *Miscanthus* x *giganteus* crops was hypothesized to have a potentially negative effect on birds preferring to feed or breed in open habitats (Anderson *et al.* 2004). A study of *Miscanthus* and *Phalaris arundinacea* fields in the first three years after establishment, (where the height of *Miscanthus* ranged from 53 – 225 cm and *Phalaris* 60 – 215 cm) recorded a higher abundance and diversity of birds within the hedges than the crop fields. The exceptions to this were the skylark, lapwing and meadow pipit *Anthus pratensis*, which were more abundant within the biomass fields. These were found predominantly in the *Miscanthus*, thought to be due to its patchy nature and the presence of areas of bare ground within the crop (Semere & Slater 2007). Bellamy *et al.* (2009) reported different findings in their work on two to three year old *Miscanthus* fields in comparison with winter wheat fields. In this case, skylarks were more abundant in the wheat fields, whereas game birds, snipe *Gallinago gallinago* and granivorous passerines were found in higher densities in the *Miscanthus* during the winter (Bellamy *et al.* 2009). The densities of birds within the *Miscanthus* crops were similar to those found in willow short rotation coppice (SRC), or set-aside fields, all of which were higher than those found in cereal crops (Bellamy *et al.* 2009). Sage *et al.* (2010) also found the assemblage of birds in *Miscanthus* similar to those found in SRC willow or scrub but at lower densities. In general they concluded that the

overall effect of *Miscanthus* plantations on bird populations was neutral, within which there were benefits for some species and detrimental effects on others.

Vepsäläinen (2010) looked specifically at *Phalaris* crops as a habitat for skylarks. Although the birds were present within the crop early in the season, as the grass grew, numbers of skylarks within it decreased, suggesting that *Phalaris* was an inferior breeding habitat. This was attributed to the unsuitability of the crop for skylark nests later in the breeding season due to closure of the crop canopy.

5.1.8 Aims

The aims of this chapter were to assess diversity and abundance of birds within the two biomass crops, using a combination of live-trapping (mist net captures) and direct observation during walking surveys. A secondary aim was to use biometric data from captured birds (such as body mass, sex and age) to further characterise traits of birds in the two crops. It was hypothesised that there would be no impact on bird diversity and abundance where the biomass crops were grown.

5.2 Materials and Methods

5.2.1 Mist netting

Bird surveys were carried out once in every two-month period from April 2008 until the end of January 2010. The same four sites across mid and west Wales and Herefordshire containing crops of the biomass grasses *Miscanthus* x *giganteus* and *Phalaris arundinacea* (as described more fully in Chapter 1) were used. A transect at 10, 20 and 50 m (where available) from the crop edge was established and a 20 m ride with a width of one metre was cut in the vegetation so that the mist net was unhindered by the crop. One 18 m long x 2.5 m high, four-shelved mist net was erected in each transect and opened up from no later than one hour after sunrise during calm, dry, mild weather. Nets were checked every 30 minutes and closed down after two hours. Birds caught were identified to species, sexed, aged (following Svensson 1992) and fitted with a uniquely numbered metal ring. Their condition was then assessed from observing tracheal pit fat deposition and pectoral muscle condition scored using the classes described in the British Trust for Ornithology (BTO) Ringer's Manual (Redfern & Clark 2001). Finally, the birds were weighed while being held immobile inside a flexible plastic cone on a balance accurate to 0.1 g (Salter, UK) before being released.

Across the four sites, a total of 35 mist netting sessions were carried out during the two years. The final session at site 'HM' took place on 27/10/08: the biomass was then mown without notice by the landowner on 19/12/08, before the December survey could be undertaken. Subsequent to that, the *Miscanthus* rhizomes in the study field were dug up and no suitable replacement field was available at the site, so surveys there ended at that point. At site 'N', harvest of the biomass crop started on 27/02/09 before the February survey was undertaken. At sites 'PP' and 'LL', harvest was originally expected to take place in April, so all survey equipment was removed in advance. However, due to weather constraints and limited availability of contractors, harvest did not take place until 05/05/09 at PP and 04/06/09 at site

'LL', which resulted in a missed survey for April 2009 at site 'LL'. The cold weather in January 2010 provided good conditions for early harvest in February and because of this, surveys were curtailed at the end of January 2010 in order for the land managers to proceed with the harvest. Due to the intermittent presence of livestock or growing crops, it was not possible to erect mist nets in the comparison plot fields at each survey, but two nets were set in the comparison plots on the six occasions that this was possible. Mist netting sessions at each site were dependent on suitable weather conditions and the order in which the different sites were surveyed varied as a result of these and other logistical factors (Table 5.1).

Table 5.1 Detail of mist netting dates at the different sites over the two survey years. + C denotes surveys where it was also possible to erect mist nets in the comparison sites.

Survey period	'LL'	'N'	'PP'	'HM'
Apr/May 2008	10/04/08	08/05/08	25/04/08	17/04/08
Jun/Jul 2008	02/07/08	16/07/08	06/06/08	02/06/08
Aug/Sep 2008	26/08/08	20/08/08	05/08/08	15/08/08
Oct/Nov 2008	17/10/08 + C	07/11/08	08/10/08	27/10/08 + C
Dec/Jan 2008	19/12/08	28/01/09	18/12/08	
Feb/Mar 2009	17/02/09		13/02/09	
Apr/May 2009		23/04/09	14/05/09	
Jun/Jul 2009	05/06/09	03/07/09 + C	09/07/09	
Aug/Sep 2009	11/08/09 + C	10/09/09	12/09/09	
Oct/Nov 2009	06/10/09 + C	28/10/09	09/11/09	
Dec/Jan 2010	18/01/10 + C	23/01/10	24/01/10	

5.2.2 Walking survey

Prior to any other disturbance on arrival at a field site for each bi-monthly survey, a walking survey of the biomass crops and comparison plots was carried out. This involved walking through and around a similar area of the fields with binoculars for the same time period, noting any birds encountered. Most birds observed were disturbed into flight, but where bird calls could be located to a particular crop, this was also counted. Any further bird species seen at other times in the fields (e.g. those encountered elsewhere whilst walking between mist nets) were also recorded. Birds such as corvids and raptors flying over the crops but not

specifically interacting with them were discounted, but swallows *Hirundo rustica* seen hawking for insects low over the crops were included in the counts.

5.2.3 Analysis

Data were analysed using the statistical package STATISTICA 10.0 (StatSoft Inc 2011). Normality of distributions were checked using the Shapiro-Wilk test. Where data were normally distributed, ANOVA (Analysis of Variance) and post-hoc Tukey HSD (Honestly Significant Difference) tests were used to determine significant differences. Where non-Gaussian distributions occurred, normalising transformations were unsuccessful, so non-parametric tests (Mann-Whitney U or Kruskal-Wallis tests) were used in these instances.

As different numbers of mist nets were used in differently sized plots, the abundance of birds caught was standardised to number per 18 m net per hour (PNPH) for statistical analyses. Bird species recorded five or more times across the whole survey period from April 2008 – January 2010 were included in analysis of any crop preference.

As bird weights varied considerably between species, a more uniform measure of body mass index (BMI) was calculated by dividing the body weight (g) by wing length (mm) (e.g. Fry & Slater 2009).

Birds recorded within the study sites were categorised as residents, summer migrants or winter migrants as designated by the British Trust for Ornithology (www.BTO.org). The same source was also used to group the birds into feeding guilds, based on their predominant dietary intake and to determine their conservation classification (red, amber or green listed).

Species diversity was measured in three ways. Firstly by a maximum species count in each area, but also by calculating Simpsons Index of Diversity, where $1- D = \Sigma(n /$

$N)^2$ and the Shannon-Wiener Index where $H' = - \Sigma (p_i \ln p_i)$ using an on-line calculator (Young 2011). Maximum diversity occurs at 1 for Simpson's Index but varies depending on species richness for the Shannon-Wiener Index ($H_{(max)} = \ln S$)..

Primary habitat associations (i.e. farmland, woodland etc) were identified for each species based on those defined in the Index of Populations of Wild Birds (DEFRA 2009).

5.3 Results

5.3.1 Mist netting and walking surveys

A total of 138 birds of 20 species were caught in the mist nets. 79 individuals of 15 species were caught in the *Miscanthus*, 57 individuals of 15 species in *Phalaris*, and 2 individuals of 2 species in the comparison plots (Table 5.2). The three most abundant species captured were the blue tit *Cyanistes caeruleus*, robin and blackbird.

Table 5.2 Abundance of the bird species caught in the mist nets in the different habitats. M = *Miscanthus*, P = *Phalaris*, CP = Comparison plots.

Species	M	P	CP	Total
Dunnock *Prunella modularis*	8	2		10
Reed warbler *Acrocephalus scirpaceus*	2	1		3
Sedge warbler *Acrocephalus schoenobaenus*	1	5		6
Chiffchaff *Phylloscopus collybita*	3	2		5
Goldcrest *Regulus regulus*	2			2
Willow warbler *Phylloscopus trochilus*		1		1
Redstart *Phoenicurus phoenicurus*	1			1
Robin *Erithacus rubecula*	18	4		22
Blackbird *Turdus merula*	9	5	1	15
Mistle thrush *Turdus viscivorus*			1	1
Song thrush *Turdus philomelos*	4	1		5
Blue tit *Cyanistes caeruleus*	18	12		30
Great tit *Parus major*	5	3		8
Long tailed tit *Aegithalos caudatus*		1		1
Treecreeper *Certhia familiaris*		1		1
Wren *Troglodytes troglodytes*	4	9		13
Reed bunting *Emberiza schoeniclus*	2	9		11
Bullfinch *Pyrrhula pyrrula*	1			1
Chaffinch *Fringilla coelebs*	1			1
Starling *Sturnus vulgaris*		1		1
Total	79	57	2	138

When calculated as mean per mist net per hour (PNPH), *Miscanthus* had the highest catch of 0.47 birds PNPH (Figure 5.1) although this was not significantly different from the 0.37 in *Phalaris* or 0.17 in the comparison plots (Kruskal-Wallis H (2, N = 74) = 3.112, $P = 0.211$).

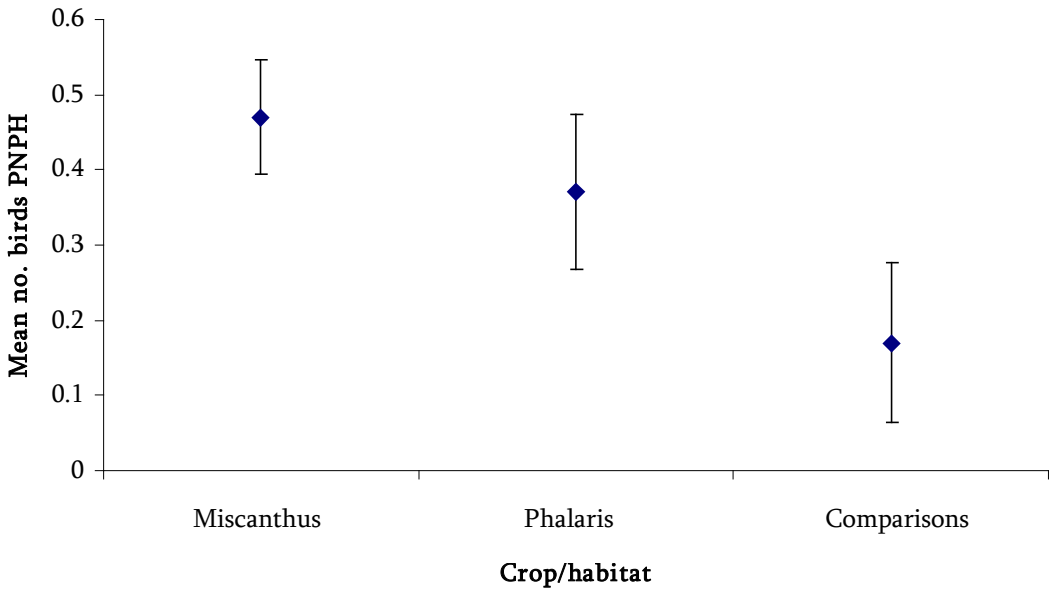

Figure 5.1 Mean catch of birds per net per hour (PNPH) ±1SE in the different areas surveyed.

When results from the walking surveys (Table 5.3) were added to those from the mist netting, a total of 37 bird species was recorded across all areas, of which 26 were in *Miscanthus*, 21 in *Phalaris* and 16 in the comparison plots. Total numbers of birds recorded in the three areas are shown in Table 5.4. The gamekeeper at 'N' also reported witnessing a goshawk *Accipiter gentilis* unsuccessfully attacking a water rail *Rallus aquaticus* in the *Phalaris*, but this sighting has not been included in the analysis.

Table 5.3 List of birds recorded during the walking surveys.

Bird species	*Miscanthus*	*Phalaris*	Comparison plots
Pheasant *Phasianus colchicus*	8	10	6
Lapwing *Vanellus vanellus*	0	0	5
Curlew *Numenius arquata*	1	0	0
Woodcock *Scolopax rusticola*	2	0	0
Great black backed gull *Larus marinus*	0	0	2
Woodpigeon *Columba palumbus*	0	0	4
Barn owl *Tyto alba*	1	0	0
Little owl *Athene noctua*	1	0	0
Skylark *Alauda arvensis*	1	0	0
Swallow *Hirundo rustica*	11	9	5
Meadow pipit *Anthus pratensis*	1	1	2
Pied wagtail *Motacilla alba*	0	0	1
Sedge warbler *Acrocephalus schoenobaenus*	1	4	0
Chiffchaff *Phylloscopus collybita*	1	0	0
Wheatear *Oenanthe oenanthe*	2	0	0
Redstart *Phoenicurus phoenicurus*	0	1	0
Robin *Erithacus rubecula*	2	0	2
Blackbird *Turdus merula*	16	3	6
Mistle thrush *Turdus viscivorus*	2	0	1
Redwing *Turdus iliacus*	0	0	10
Song thrush *Turdus philomelos*	3	4	4
Blue tit *Cyanistes caeruleus*	1	0	0
Great tit *Parus major*	1	0	0
Wren *Troglodytes troglodytes*	2	9	0
Reed bunting *Emberiza schoeniclus*	5	12	2
Chaffinch *Fringilla coelebs*	0	1	0
Starling *Sturnus vulgaris*	0	0	20
Magpie *Pica pica*	0	1	0
Carrion crow *Corvus corone*	1	0	4
Jackdaw *Corvus monedula*	0	0	14
Total	**63**	**55**	**88**

Table 5.4 The total numbers of individual birds (of all species) and the number of individual species recorded in the different habitats, based on both mist net captures and walking surveys. NB: where the same species was seen on walking survey and also caught in mist nets, the highest number seen (or ringed) in either survey was recorded (rather than the sum of the two), to exclude duplicate records where birds observed on the walking survey were subsequently captured and ringed.

Habitat	Total birds recorded	No. of species
Miscanthus	134	26
Phalaris	96	21
Comparison plots	88	16

A number of bird species were recorded only in a single habitat or at a single site (Table 5.5).

Table 5.5 Bird species recorded in only one habitat or at only one site when surveyed using a combination of mist netting and walking surveys. Numbers in parentheses indicate the number of the species recorded by both survey techniques.

Site Habitat	N	LL	PP	HM
Miscanthus	Curlew (1) Woodcock (1) Barn owl (1) Skylark (1) Meadow pipit (1) Reed warbler (2) Sedge warbler (6) Goldcrest (1) Bullfinch (1)		Woodcock (1) Goldcrest (1)	Little owl (1) Wheatear (2)
Phalaris	Meadow pipit (1) Reed warbler (1) Sedge warbler (6)	Willow warbler (1) Long tailed tit (1) Treecreeper (1)	Magpie (1)	
Comparison plots	Great black-backed gull (2) Meadow pipit (2)	Pied wagtail (1) Redwing (10)		Lapwing (5) Woodpigeon (4) Jackdaw (14)

Detectability of a bird species by the two survey methods partly depended on the crop type; in *Miscanthus*, a greater number of species were detected during walking transects than by mist netting, whereas the opposite occurred in *Phalaris* (Figure 5.2). Furthermore, Figure 5.2 also shows that the cumulative species count

continued to increase throughout the series of surveys: even on the final survey, a new species was detected in each crop.

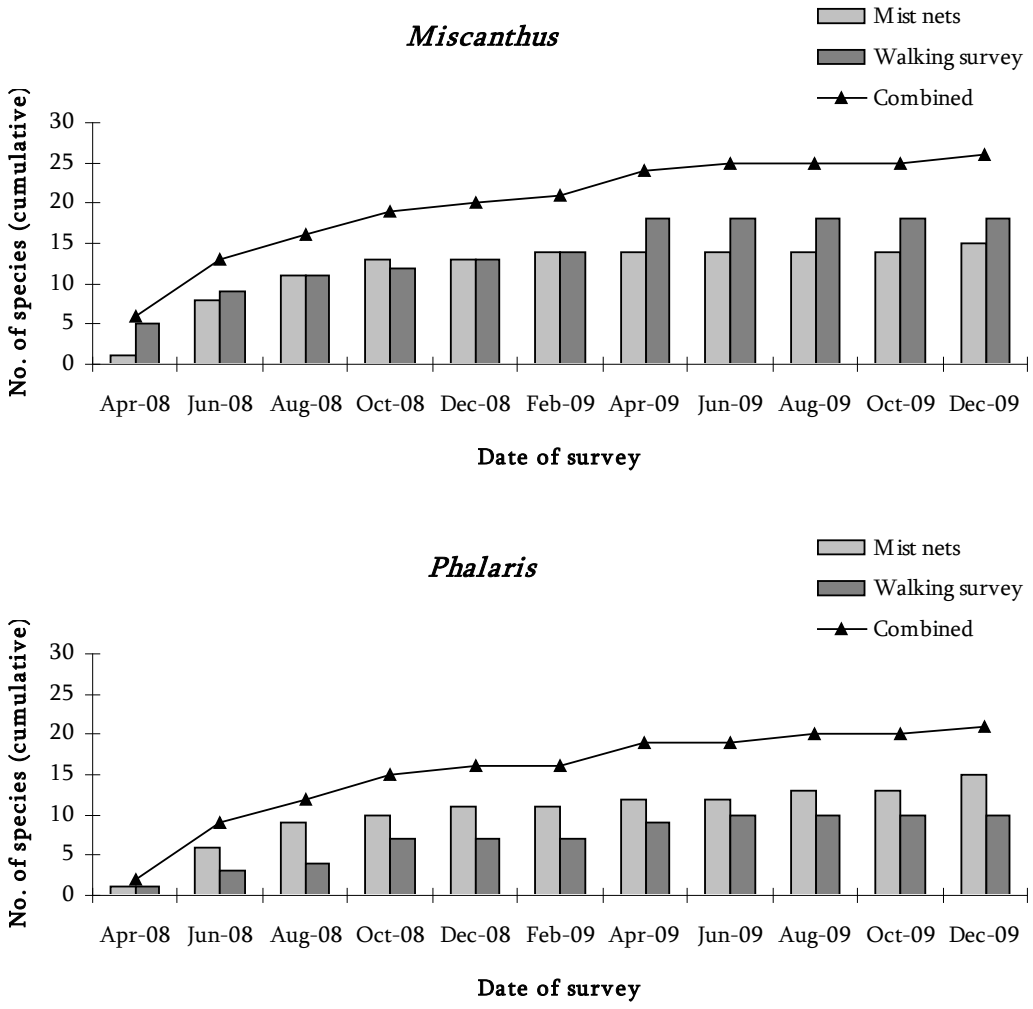

Figure 5.2 Species accumulation curve for the two biomass crops, showing individual numbers for mist netting and walking survey and the cumulative numbers of species detected using a combination of the two survey techniques.

Table 5.6 details species detected by one or other, or both survey techniques.

Table 5.6 The efficiency of walking surveys and mist-netting in terms of uniqueness of species detected by each means.

Miscanthus			*Phalaris*		
Walking survey only	Mist nets only	Detected by both	Walking survey only	Mist nets only	Detected by both
Pheasant	Dunnock	Sedge warbler	Pheasant	Dunnock	Sedge warbler
Barn owl	Reed warbler	Chiffchaff	Swallow	Reed warbler	Blackbird
Curlew	Goldcrest	Robin	Meadow pipit	Chiffchaff	Song thrush
Woodcock	Redstart	Blackbird	Redstart	Willow warbler	Wren Reed bunting
Little owl	Bullfinch	Song thrush	Chaffinch	Robin	
Skylark	Chaffinch	Blue tit	Magpie	Blue tit	
Swallow		Great tit		Great tit	
Meadow pipit		Wren		Long-tailed tit	
Wheatear		Reed bunting		Treecreeper	
Mistle thrush				Starling	
Carrion crow					

5.3.2 Crop/habitat preference

In terms of total numbers of birds caught per net per hour (PNPH), there was no significant difference in catch between the two crops or comparison plots (Kruskal-Wallis H (2, N = 74) = 3.112 P = 0.211). Neither was any individual bird species trapped in significantly higher abundance in one habitat than another (Table 5.7).

Table 5.7 Mann-Whitney U Test results for individual bird species PNPH in the two biomass crops. Analysis only includes those species recorded five or more times.

	Phalaris		*Miscanthus*				
	Rank Sum	Valid N	Rank Sum	Valid N	U	Z - value	P - value
Blackbird	1035	32	1312	36	507	-0.85	0.40
Blue tit	1066	32	1280	36	538	-0.46	0.64
Chiffchaff	1107	32	1239	36	573	0.03	0.98
Dunnock	1090	32	1257	36	562	-0.17	0.86
Reed bunting	1110	32	1237	36	571	0.06	0.95
Reed warbler	1090	32	1256	36	562	-0.17	0.87
Robin	1030	32	1316	36	502	-0.90	0.37
Sedge warbler	1125	32	1222	36	556	0.25	0.81
Song thrush	1142	32	1204	36	538	0.46	0.64
Wren	1175	32		36	505	0.87	0.39

5.3.3 Distance into crop

When the position of the net in which the birds were caught was taken into account, significantly higher numbers were trapped in the 10 m transect than the 20 m (but not the 50 m transect) in *Miscanthus*, Kruskal-Wallis ANOVA by ranks $P = 0.027$ (Table 5.8).

Table 5.8 P – values for pairwise post-hoc comparisons of the total number of birds caught in the different transects in *Miscanthus*: Kruskal-Wallis H (2, N = 84) = 8.083 $P = 0.018$.

Transect	10 m	20 m	50 m
10 m		0.027	0.599
20 m	0.027		1.000
50 m	0.599	1.000	

Although it appeared that the 10 m transect in *Phalaris* also contained more birds than either of the other two transects, this was not a statistically significant result (Kruskal-Wallis H (2, N = 93) = 3.255 $P = 0.197$, Figure 5.3).

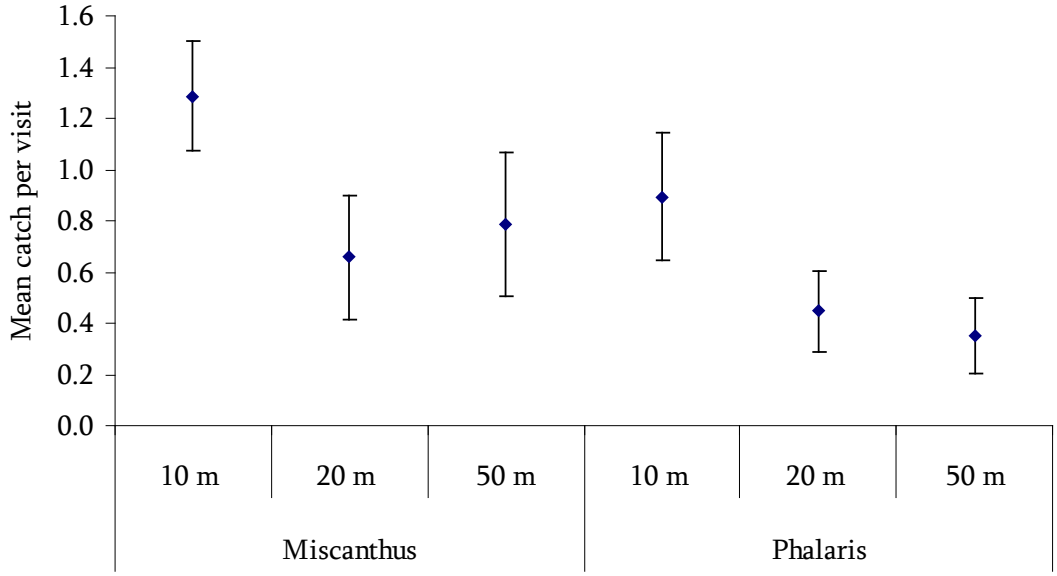

Figure 5.3 Mean catch of birds ±1SE per visit per transect in both biomass crops.

When tested for individual species, no further significant distance / edge effects were seen, although some species did show considerable (but non-significant) variation in where they were caught (Figure 5.4).

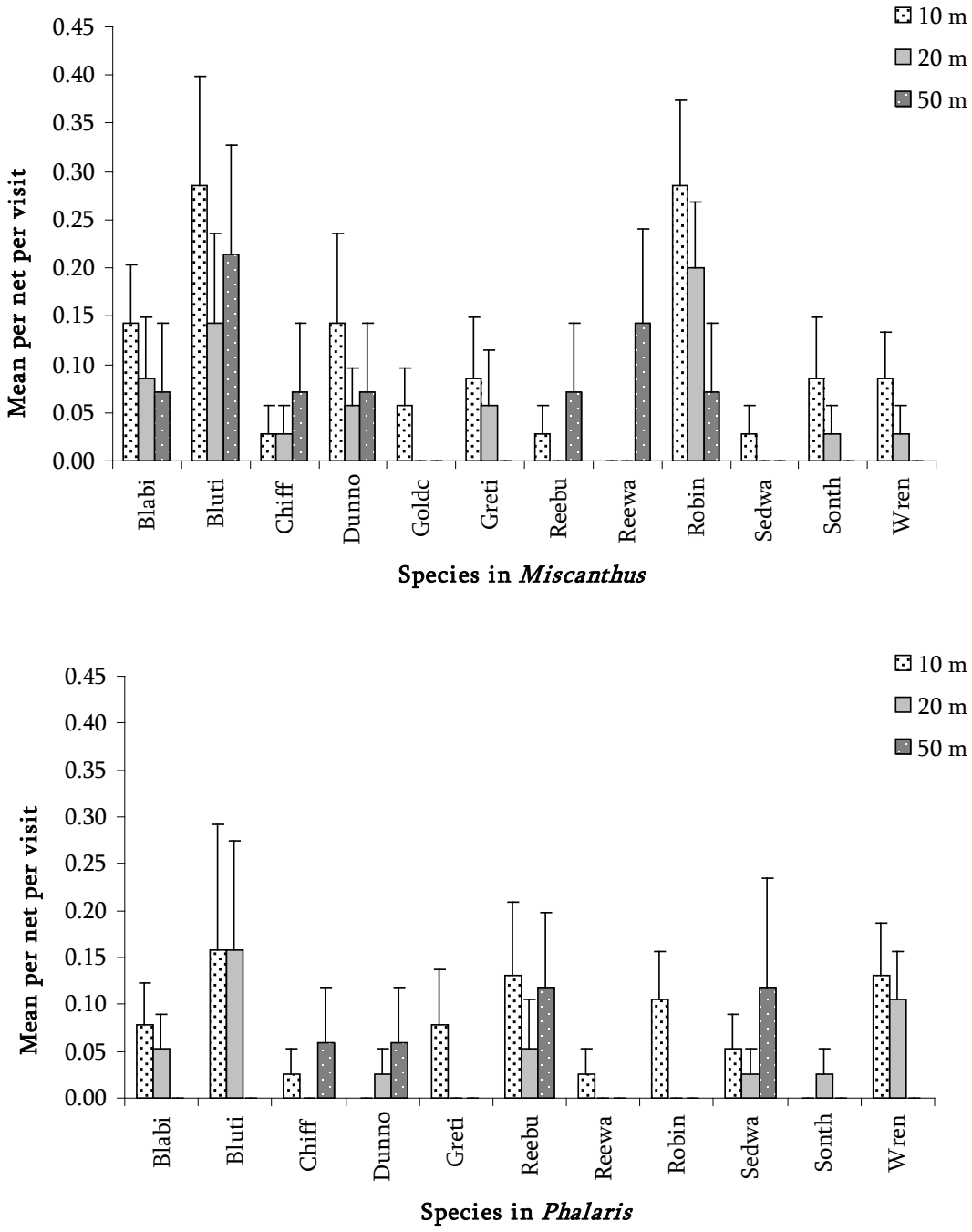

Figure 5.4 Distribution (by transect) of the most commonly captured birds in the biomass crops. Figures shown are means per net per visit +1SE. Abbreviations: Blabi = blackbird, Bluti = blue tit, Chiff = chiffchaff, Dunno = dunnock, Greti = great tit, Reebu = reed bunting, Reewa = reed warbler, Sedwa = sedge warbler, Sonth = song thrush.

5.3.4 Age and sex

Sex was determined in 74 birds, 38 of which were female and 36 male. Chi-squared tests showed no significant differences in the abundance of either sex in either crop (Table 5.9).

Table 5.9 Chi-squared (χ^2) results for male and female birds in the two biomass crops.

	No. male birds	No. female birds	χ^2	*df*	*P* - value
Miscanthus	23	25	0.083	1	0.773
Phalaris	13	13	0	1	>0.999

For the birds in which age could be determined, there was no significant difference in the crop in which they were caught, for birds either <1 year or >1 year in age (Kruskal-Wallis H (1, N = 72) = 0.109, $P = 0.742$ and H (1, N = 72) = 0.297, $P = 0.586$ respectively).

5.3.5 Recaptures

As each individual bird captured in mist nets was fitted with a uniquely coded ring, it was possible to identify them if they were caught at a subsequent survey. 12 of the birds caught in mist nets at the biomass crop sites had previously been ringed: five of these at a feeder within 1 km of the crops at site 'LL' and one at an unknown location. Six birds had been previously ringed within the biomass crops, and details of time elapsed between captures, changes in location and weight are shown in Table 5.10.

Table 5.10 Detail of the individual birds recaptured within the biomass crops (site, crop, transect). M = *Miscanthus,* P = *Phalaris*.

Species & unique ring no.	Where / when caught initially	Where / when re-trapped	Days elapsed between captures	Weight difference
Reed bunting V760299	'N' M 10 m 20/08/08	'N' P 10 m 28/01/09	161	-0.5 g
Blue tit V760324	'LL' P 10 m 17/10/2008	'LL' P 20 m 14/11/08	28	+1.3 g
Robin V760328	'LL' P 10 m 17/10/08	'LL' M 20 m 14/01/09	89	+3.1 g
Robin V760387	'LL' M 10 m 19/12/08	'LL' P 10 m 05/06/09	168	-1.2 g
Blue tit V760725	'LL' M 10 m 06/10/09	'LL' M 20 m 18/01/10	104	0g
Robin V760726	'N' M 20 m 28/10/09	'N' M 50 m 23/01/2010	87	+1.5 g

5.3.6 Feeding ecology

As a group, obligate invertebrate feeders showed a significant difference in abundance between the three habitat types (Kruskal-Wallis H (2, N = 101) = 6.876 P = 0.032), but on pairwise comparison, no significant differences between individual habitats were seen. Birds with diets including both invertebrates and fruit/berries were found in significantly different abundances in the three habitats (Kruskal-Wallis H (2, N = 101) = 9.126, P = 0.01). Pairwise comparisons (adjusted for multiple comparisons) showed a higher abundance of this group in the *Miscanthus* than the comparison plots (P = 0.03), but no significant differences were seen between the comparison plots and the *Phalaris* crop (P = 0.949). Those with a diet of invertebrates and seeds were also significantly more abundant in the biomass crops than the comparison plots (Kruskal-Wallis H (2, N = 101) = 31.355, P < 0.0001). Pairwise comparisons (adjusted for multiple comparisons) showed significantly less of the invertebrate/seed group in the comparison plots than in the *Miscanthus* (P < 0.0001) or *Phalaris* crop (P = 0.001).

5.3.7 Condition scores

Body mass index (BMI = weight divided by wing length) was tested against date, species and crop type. Although BMI varied throughout the year, this was not significant result (ANOVA $F_{(5, 121)} = 1.543$, $P = 0.182$, Figure 5.5). Neither was there any significant difference between the BMI of birds caught in the two biomass crops ($F_{(1, 126)} = 0.396$, $P = 0.530$).

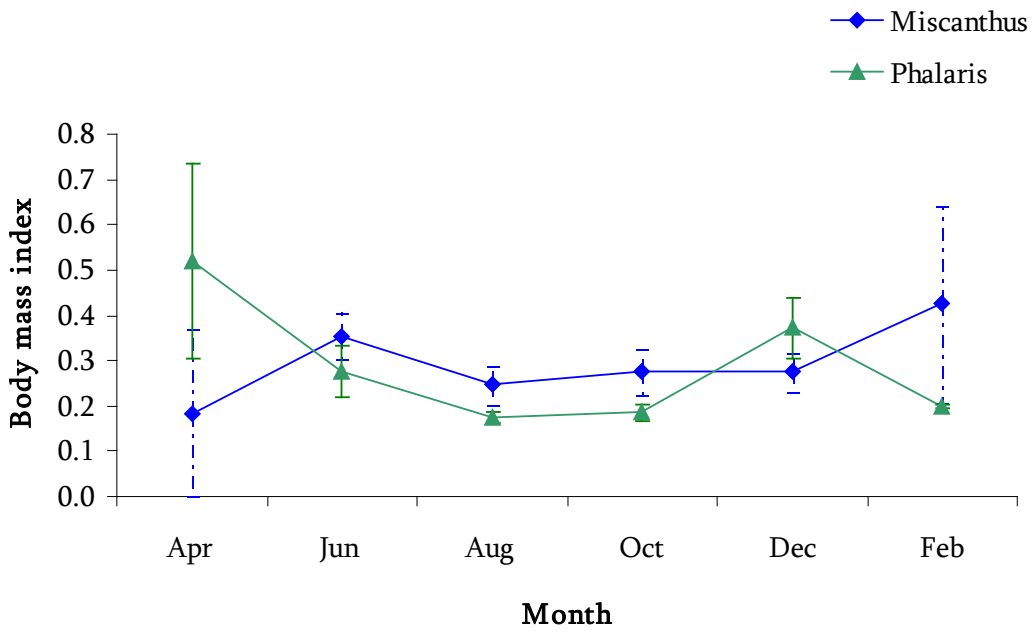

Figure 5.5 Seasonal changes in body mass index (BMI) of birds within both biomass crops over one year. Values shown are means ±1SE.

5.3.8 Diversity of bird species

Species richness (total number of species recorded) across all sites and crops was lower in the second year of surveys than the first (ANOVA $F_{(1, 28)} = 11.428$, $P = 0.022$). There was also a significant difference in species richness between habitats ($F_{(2, 28)} = 11.657$, $P < 0.001$, Table 5.11). When examined further using a Tukey HSD post-hoc test, it revealed that both *Miscanthus* and *Phalaris* contained more species than the comparison plots ($P < 0.001$ and $P = 0.013$ respectively). There was a non-significant temporal difference between the months in which

surveys were carried out: the lowest observed species richness occurred in February and the highest occurred in June.

Table 5.11 The three measures of biodiversity within the different habitats. Maximum diversity occurs at 1 for Simpson's Index of Diversity and 3.5 for the Shannon-Wiener Index. Figures shown are scores calculated from the total number of each species within each habitat across all sites and all dates and the mean of the Simpson and Shannon scores for each visit. On visits where there was a zero bird count or only 1 species present, no diversity score could be calculated and these were omitted from calculations.

		Shannon-Wiener index		Simpson's index	
	Species no.	Habitat	Mean	Habitat	Mean
Miscanthus	26	2.32	1.09	0.97	0.96
Phalaris	21	2.19	0.98	0.95	0.92
Comparison plots	15	1.72	0.88	0.88	0.89

Diversity scores could not be calculated for visits where only one or no bird species were detected and these visits were therefore omitted from analysis. Both Shannon and Simpson's diversity scores were highest in the *Miscanthus* and lowest in the comparison plots (Figure 5.6).

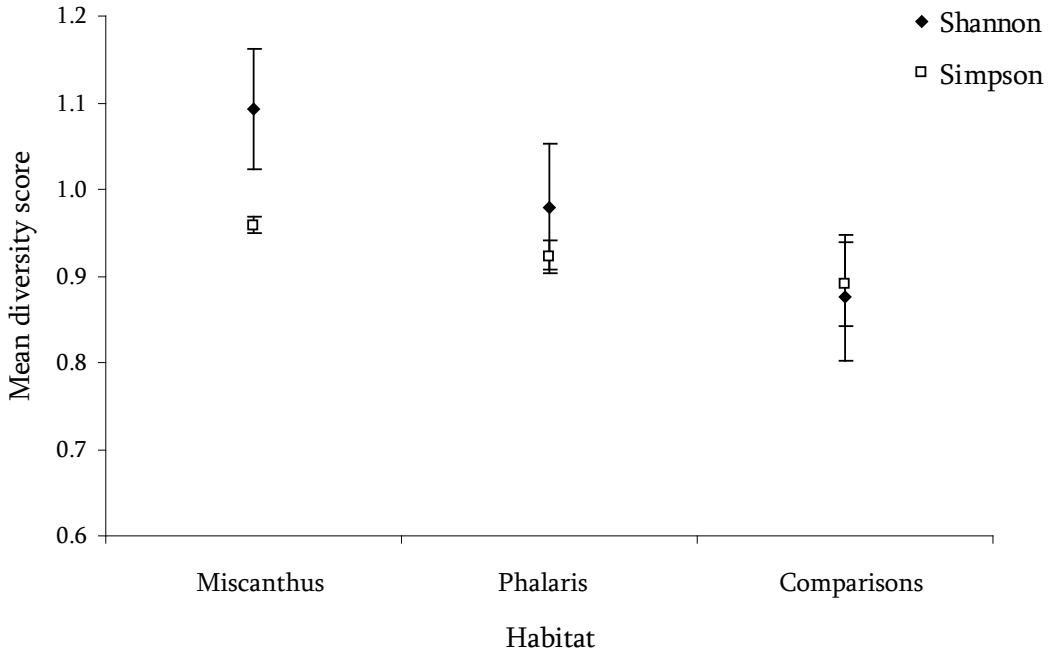

Figure 5.6 Mean (±1SE) Simpson's Index of Diversity and Shannon-Wiener scores for the three habitats.

Non-significant seasonal differences also occurred for each diversity index, whereby Shannon scores were highest in autumn and Simpson's scores in spring.

5.3.9 Species of conservation concern

Four red-listed bird species (lapwing, starling, song thrush and redwing) were recorded in the comparison plots – more than in either of the biomass crops, although there was a high variability in the abundance of these species in the comparison plots and the difference between habitats was not statistically significant. For amber-listed species, *Miscanthus* appeared to be more favourable than any other habitat (Table 5.12), but this was not a statistically significant difference (Kruskal-Wallis H (2, N = 99) = 5.052, P = 0.08). For a full list of conservation status designations for the birds caught, see Appendix 2.

Table 5.12 The number of species in the different conservation designations in the different habitats.

Designation	*Miscanthus*	*Phalaris*	Comparison plots
Red list	2	2	4
Amber list	10	5	5
Green list	12	13	6
No designation	2	1	1

5.3.10 Habitat associations and habitat specialists

A full list of the habitat association designations (DEFRA 2009) of the birds recorded in this study is shown in Table 5.13.

Table 5.13 Habitat associations as defined in the Index of Populations of Wild Birds (DEFRA 2009). Species deemed to be specialists in that habitat are listed in *italics*.

Woodland	Farmland	Upland	Lowland wetland	Other/non-classified
Blackbird	*Jackdaw*	Curlew	Reed warbler	Barn owl
Blue tit	*Lapwing*	Meadow pipit	Sedge warbler	Barn swallow
Bullfinch	Little owl	Wheatear		Carrion crow
Chaffinch	Reed bunting			Great black backed gull
Chiffchaff	*Skylark*			Magpie
Dunnock	*Starling*			Mistle thrush
Goldcrest	Woodpigeon			Pheasant
Great tit				Pied wagtail
Long tailed tit				Redwing
Redstart				Woodcock
Robin				
Song thrush				
Treecreeper				
Wren				
Willow warbler				

Most of the bird species recorded in the biomass crops were considered to be woodland species rather than farmland species (Figure 5.7). In comparison with the comparison plots, the abundance of woodland birds was significantly different in the biomass crops (Kruskal-Wallis H (2, N = 101) = 32.004, $P < 0.0001$). Pairwise comparisons (adjusted for multiple comparisons) showed that both *Miscanthus* and *Phalaris* crops contained a higher abundance of woodland birds than the comparison plots ($P < 0.0001$ and $P = 0.001$ for *Miscanthus* and *Phalaris* respectively). Although there was a higher abundance of farmland birds in the comparison plots than the biomass crops, variance in abundance was high and there was no significant difference between the comparison plots and the biomass crops (Kruskal Wallis H (2, N = 101) = 3.127, $P = 0.209$).

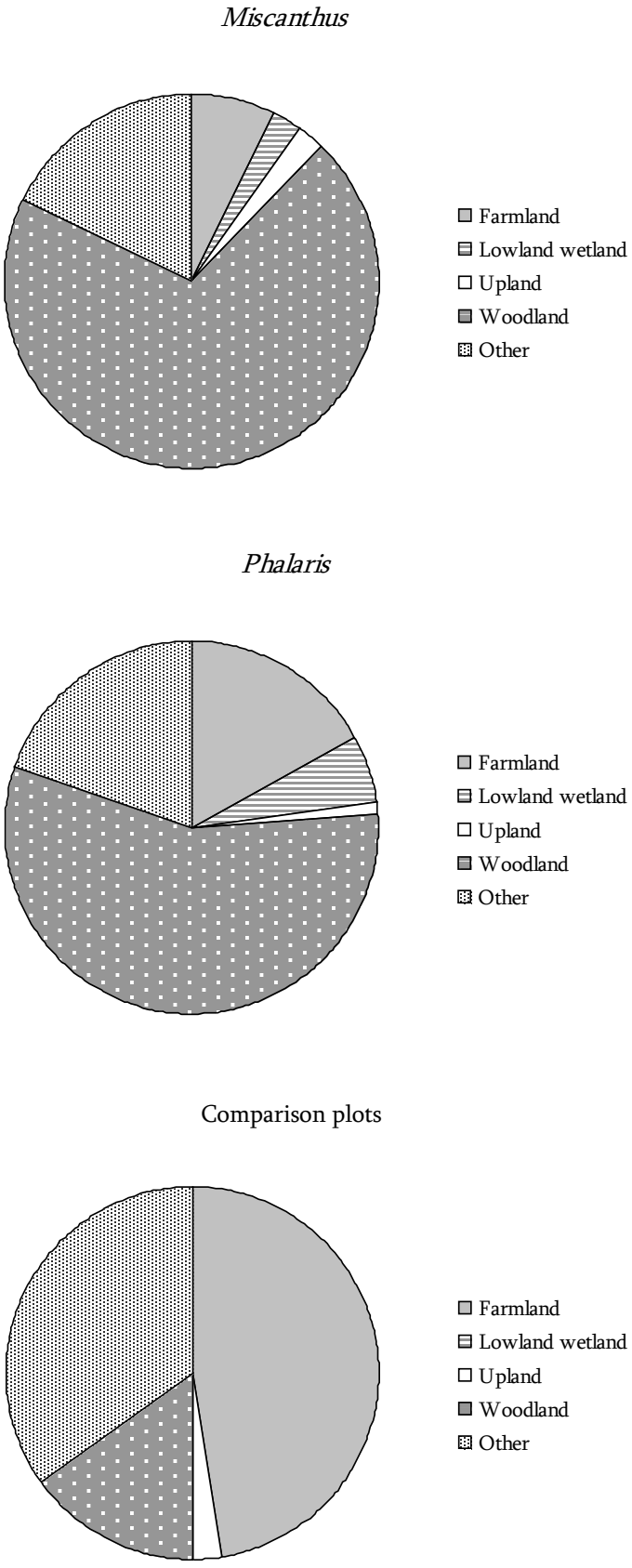

Figure 5.7 Proportions of the birds with different habitat associations in each habitat.

5.3.11 Seasonal changes and the influence of migrants

With the influence of both summer and winter migrant species, both the number of species and counts of individual birds in the different habitats varied between winter and the breeding season (Table 5.14).

Table 5.14 Species and individual counts during both the breeding season (summer) and winter.

	Species count		Individual count	
Habitat	Winter	Breeding season	Winter	Breeding season
Miscanthus	15	20	58	76
Phalaris	13	16	40	56
Comparison plots	7	13	39	50

Total catch of birds PNPH were significantly different between survey months (Kruskal-Wallis H (5, N = 68), $P = 0.035$. The lowest numbers of birds PNPH were recorded in April, and the highest in December and February, and there was a significant difference between the counts in April and December (pairwise comparison adjusted for multiple comparisons $P = 0.028$). The abundance of only two species varied significantly with the months in which they were caught. Reed warblers were caught in higher abundance in the August surveys (Kruskal-Wallis H (5, N = 68) = 18.813, $P = 0.002$) and wrens in December and February surveys Kruskal-Wallis H (5, N = 68), $P = 0.023$ respectively).

The classification of migrant and resident birds is shown in Table 5.15. The percentage of resident birds found in all three habitats was similar, but when tested, both *Phalaris* and *Miscanthus* held significantly higher percentages of resident birds than the comparison plots (Kruskal-Wallis H (2, N = 101) = 15.105, $P = 0.019$ and $P < 0.001$ respectively). The two biomass crops had similar numbers of summer migrants, but no winter migrants. Conversely, the comparison plots had more winter than summer migrants (Table 5.16), but despite this trend, no significant differences existed between habitats for either summer migrants (Kruskal-Wallis

test: H (2, N = 101) = 5.464 $P = 0.065$) or winter migrants (Kruskal-Wallis test: H (2, N = 101) = 1.886, $P = 0.390$).

Table 5.15 Migrant or resident status of the birds recorded within the study sites (as classified by BTO).

Resident		Summer migrants	Winter migrants
Barn owl	Magpie	Chiffchaff	Redwing
Blackbird	Meadow pipit	Redstart	
Blue tit	Mistle thrush	Reed warbler	
Bullfinch	Pheasant	Sedge warbler	
Carrion crow	Pied wagtail	Swallow	
Chaffinch	Reed bunting	Wheatear	
Curlew	Robin	Willow warbler	
Dunnock	Skylark		
Great black-backed gull	Song thrush		
Goldcrest	Starling		
Great tit	Treecreeper		
Jackdaw	Woodcock		
Lapwing	Wood pigeon		
Long-tailed tit	Wren		

Table 5.16 The percentage of resident and migrant birds in the three habitats.

	Resident	Summer migrant	Winter migrant
Miscanthus	84%	16%	0
Phalaris	83%	17%	0
Comparison plots	82%	5%	13%

5.3.12 Bird taxonomic groupings

The species contained in each group are detailed in Table 5.17.

Table 5.17 Categories of the birds used in the analysis and the species they contain.

Group	Species within group
Corvids	Crow, jackdaw, magpie
Dunnocks/wrens	Dunnock, treecreeper, wren
Finches/buntings	Bullfinch, chaffinch, reed bunting
Owls	Barn owl, little owl
Pheasants/pigeons	Pheasant, wood pigeon
Pipits/wagtails	Meadow pipit, pied wagtail
Larks	Skylark
Swallows	Swallow
Thrushes	Blackbird, mistle thrush, redstart, redwing, robin, song thrush, starling, wheatear
Tits	Blue tit, great tit, long tailed tit
Waders/seabirds	Curlew, lapwing, great black-backed gull, woodcock
Warblers	Chiffchaff, goldcrest, reed warbler, sedge warbler, willow warbler

Some bird taxonomic groups were found in significantly different numbers in the three different habitats (Table 5.18 and Figure 5.8). Both dunnocks/wrens and finches/buntings were found only in the biomass crops and not in the comparison plots, accounting for the significant differences. Only one group (pipits/wagtails) recorded in all three habitats, were seen significantly more in the comparison plots than the biomass crops. Waders/seabirds were also significantly more abundant in the comparison plots than in the *Miscanthus* but were not recorded at all in the *Phalaris*. The only significant preference between the two biomass crops was shown by thrushes/starlings, which were recorded in greater numbers in *Miscanthus* (Kruskal-Wallis H (1, N = 68) = 5.102 $P = 0.024$).

Table 5.18 Kruskal Wallis ANOVA by ranks showing the bird groups in which significant differences existed between the different habitats.

	H value (df 2, N = 82)	*P* - value
Dunnocks/wrens	7.329	0.026
Finches/buntings	6.044	0.049
Pipits/wagtails	6.849	0.033
Waders/seabirds	8.012	0.018

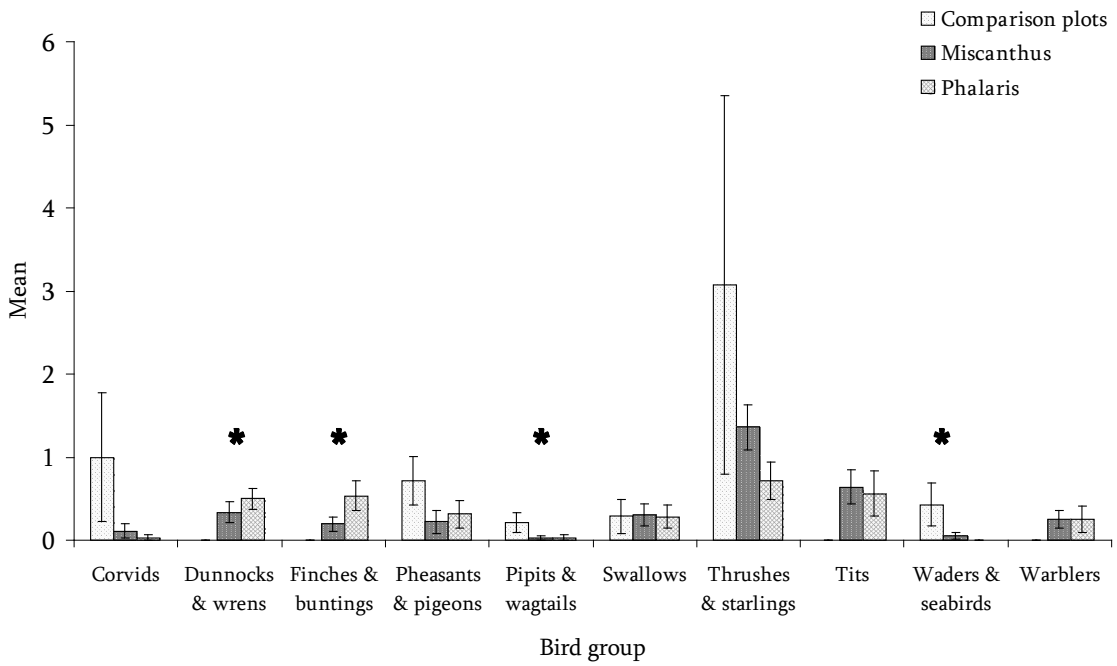

Figure 5.8 Abundance of the different bird groupings in the three habitats. Figures shown are mean number per visit ±1SE and significant differences ($P < 0.05$) between habitats are indicated by ✱.

5.4 Discussion

A higher abundance and diversity of birds was found in *Miscanthus* crops than *Phalaris* crops, although both crops appeared to provide good habitat for birds, particularly those normally associated with woodland or reedbed habitat.

5.4.1 Effectiveness of mist netting and walking surveys

The lack of availability of the comparison plots for mist-netting at every survey may have influenced the results in terms of the accuracy of estimates of comparison plot bird abundance in comparison with the biomass crops. However, when the comparison plots (in the form of grazed grass fields or barley) were used, the mist nets were visibly obvious to the human eye (and therefore also likely to be visible to birds), whereas nets within the biomass crops, particularly *Miscanthus* were much less detectable (Figure 5.9). The small number of birds captured in the comparison plots could either have been a true measure of what was there or simply due to any birds present avoiding the highly visible nets. Variability in the bird abundance recorded during walking surveys was also very high, particularly in the comparison plots, where sometimes no birds were recorded at all and at other times a whole flock was present. Logistics and funding dictated that surveys were only carried out bi-monthly, but more regular surveys of longer duration may have produced less variable results.

Figure 5.9 Photographs of mist nets in operation in *Phalaris* (left) and *Miscanthus* (right) at site 'PP'.

Previous studies on birds in *Miscanthus* (Sage *et al.* 2010; Bellamy *et al*. 2009) and *Miscanthus* and *Phalaris* (Semere & Slater 2005) have relied purely on walking census techniques, whereby birds seen or heard whilst a surveyor walks through a habitat are recorded. It is apparent that adding in mist nets to the sampling protocol allowed the detection of additional species that were not recorded on walking surveys (Table 5.7). This was particularly noticeable in the *Phalaris*, where 10 species were detected by the use of mist nets alone, 6 unique species were detected in the walking surveys and 5 species detected by both means. It was also noted, however, that the resident reed bunting flocks at sites 'LL' and 'N' actively avoided mist nets in the *Phalaris* by the second year: they were often seen flying over or around the nets if disturbed by the surveyor on a mist net round. Generally, more reed buntings were seen than caught and those captured tended to be juveniles that were likely to be naïve to capture in mist nets. This potential learned avoidance of mist nets may mean that the data collected through their use may not be a true indication of bird abundance (Remsen & Good 1996). For this reason, no attempt was made to calculate bird population densities and only their presence or absence in each field was noted. However, the use of both mist nets and walking surveys increased the range of bird species detected and as such are an optimal combination.

In the *Miscanthus*, walking surveys remained a more effective way of detecting bird species than the mist nets. This was particularly true for the larger birds such as the corvids, waders and owls (although the little owl was seen perching on a mist net pole!). Many of the additional species detected in *Miscanthus* during walking surveys were seen soon after harvest, (when stubble or short new growth was present), rather than later in the growing season. The way in which birds were detected in the full-grown biomass crops during walking surveys was different in each crop, due to the different vegetative structure. In the *Phalaris* crop, reed buntings and wrens were often seen moving between different parts of the crop,

and if disturbed, would fly a short distance before settling back into the crop vegetation. Within the *Miscanthus*, some birds were detected by their alarm calls, or from being seen flying into the crop from elsewhere on the surveyor's approach, as well as being seen directly in the crop.

5.4.2 Crop preference

In total, *Miscanthus* appeared to contain a higher abundance of birds compared to the *Phalaris* and comparison plots, even if this difference was not statistically significant. It also contained a higher total number of species across the whole year (26 species) than either the comparison plots or the *Phalaris* crops. The number of species present in *Miscanthus* crops was 15 in winter and 20 in summer. The species richness in the biomass crops in the present study, though partially dependent on observer effort, is comparable with other work on birds in *Miscanthus* in the UK (Table 5.19).

Table 5.19 Details from previously published studies on bird species numbers recorded in *Miscanthus* in either the breeding (B) season (summer) or non-breeding (NB) season (winter).

Source	Area surveyed	Type of crop	Total spp.	NB	B
Sage *et al.* (2010)	SW England	'Mature'	26	20	14
Bellamy *et al.* (2009)	Cambridgeshire	1 – 4 yrs old	37	24	24
Semere & Slater (2005)	Herefordshire	Newly planted – 2 yrs old	26	13	24
Current study	Mid and west Wales and Herefordshire	Mature (>3 years old)	27	15	20

Despite the geographical differences between the other published studies and this one, many species were found in common. Eight species were reported as present by all four studies and a further 13 species were recorded in three out of the four (Tables 5.20 (a) and (b)).

Table 5.20 (a) and **(b)** Species data from previously published work on birds in *Miscanthus* in the UK in comparison with the present study, in order of abundance. NB = non=breeding season / winter and B = breeding season / summer. Species recorded in at least three of the four studies are in bold (a) and in two studies or less, normal type (b).

(a)	Bellamy *et al.* 2009		Sage *et al.* 2010		Semere & Slater 2005		Current study	
Species	NB	B	NB	B	NB	B	NB	B
Blackbird *Turdus merula*	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Carrion crow *Corvus corone*	**Y**	**Y**		**Y**	**Y**	**Y**		**Y**
Chaffinch *Fringilla coelebs*	**Y**		**Y**	**Y**	**Y**	**Y**	**Y**	
Jackdaw *Corvus monedula*		**Y**		**Y**		**Y**	**Y**	
Meadow pipit *Anthus pratensis*	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**		**Y**
Pheasant *Phasianus colchicus*	**Y**	**Y**	**Y**		**Y**	**Y**	**Y**	**Y**
Skylark *Alauda arvensis*	**Y**	**Y**		**Y**	**Y**	**Y**		**Y**
Wren*Troglodytes troglodytes*	**Y**		**Y**			**Y**	**Y**	
Blue tit*Cyanistes caeruleus*			**Y**		**Y**		**Y**	**Y**
Dunnock *Prunella modularis*		**Y**	**Y**	**Y**			**Y**	**Y**
Great tit *Parus major*		**Y**				**Y**	**Y**	**Y**
Linnet *Carduelis cannabina*	**Y**	**Y**	**Y**		**Y**	**Y**		
Red-legged partridge *Alectoris rufa*	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**		
Reed bunting *Emberiza schoeniclus*	**Y**	**Y**	**Y**	**Y**			**Y**	**Y**
Reed warbler *Acrocephalus scirpaceus*		**Y**	**Y**	**Y**				**Y**
Robin *Erithacus rubecula*			**Y**		**Y**		**Y**	**Y**
Song thrush *Turdus philomelos*	**Y**	**Y**	**Y**				**Y**	**Y**
Woodcock *Scolopax rusticola*	**Y**		**Y**				**Y**	
Woodpigeon *Columba palumbus*		**Y**		**Y**	**Y**	**Y**		
Yellow wagtail *Motacilla flava*		**Y**		**Y**	**Y**	**Y**		
Yellowhammer	**Y**	**Y**	**Y**	**Y**		**Y**		

(b)	Bellamy *et al.* 2009		Sage *et al.* 2010		Semere & Slater 2005		Current study	
Species	NB	B	NB	B	NB	B	NB	B
Fieldfare *Turdus pilaris*	Y					Y		
Goldfinch *Carduelis carduelis*			Y		Y	Y		
Greenfinch *Carduelis chloris*	Y			Y				
Grey partridge *Perdix perdix*	Y				Y	Y		
House sparrow *Passer domesticus*	Y				Y	Y		
Mistle thrush *Turdus viscivorus*						Y		Y
Pied wagtail *Motacilla alba*			Y		Y	Y		
Sedge warbler *Acrocephalus schoenobaenus*		Y						Y
Snipe *Gallinago gallinago*	Y		Y					
Stock dove *Columba oenas*		Y				Y		
Whitethroat *Sylvia communis*		Y				Y		
Barn owl *Tyto alba*								Y
Bullfinch *Pyrrhula pyrrhula*							Y	
Chiffchaff *Phylloscopus collybita*								Y
Common redpoll *Carduelis flammea*	Y							
Corn bunting *Emberiza calandra*	Y	Y						
Curlew *Numenius arquata*							Y	
Goldcrest *Regulus regulus*							Y	
Jay *Garrulus glandarius*		Y						
Kestrel *Falco tinnunculus*	Y							
Lapwing *Vanellus vanellus*					Y	Y		
Lesser redpoll *Carduelis cabaret*	Y							
Little owl *Athene noctua*								Y
Long-tailed tit *Aegithalos caudatus*			Y					
Magpie *Pica pica*		Y						
Mallard *Anas platyrhynchos*		Y						
Moorhen *Gallinula chloropus*	Y							
Redstart *Phoenicurus phoenicurus*								Y
Redwing *Turdus iliacus*	Y							
Rook *Corvus frugilegus*		Y						
Sparrowhawk *Accipiter nisus*	Y							
Starling *Sturnus vulgaris*						Y		
Stonechat *Saxicola torquatus*			Y					
Swallow *Hirundo rustica*								Y
Wheatear *Oenanthe oenanthe*								Y

Only one other study of birds has been conducted in *Phalaris* in the UK (Semere & Slater 2005). Their results are compared to this study in Table 5.21. Only six species were reported in both studies, none of which are considered to be unusual on farmland. It is possible that birds regard *Phalaris* crops in a similar way to a hay or cereal crop in the way in which they utilise the habitat. This possibility is supported by Vepsäläinen (2010), who found that there was no difference between *Phalaris* and conventionally cultivated crops for the most abundant bird species found within them. In the current study however, reed buntings were seen more

often and in higher abundance in the *Phalaris* than the adjacent spring barley field at one of the sites, suggesting a preference for the *Phalaris*.

Table 5.21 Species data from the only previously published work on birds in *Phalaris* in the UK in comparison with this study in order of abundance. NB = non=breeding season / winter and B = breeding season / summer. Species recorded in both the studies are in bold.

	Semere & Slater 2005		Current study	
	NB	B	NB	B
Pheasant	**Y**	**Y**	**Y**	**Y**
Wren	**Y**	**Y**	**Y**	**Y**
Blue tit		**Y**	**Y**	**Y**
Chaffinch	**Y**	**Y**	**Y**	
Meadow pipit	**Y**			**Y**
Blackbird	**Y**	**Y**	**Y**	**Y**
Great tit			Y	Y
Linnet	Y	Y		
Red-legged partridge	Y	Y		
Reed bunting			Y	Y
Robin			Y	Y
Skylark	Y	Y		
Song thrush			Y	Y
Blackcap		Y		
Carrion crow		Y		
Chiffchaff				Y
Dunnock			Y	
Grey partridge	Y			
Long-tailed tit				Y
Magpie				Y
Mistle thrush		Y		
Pied wagtail		Y		
Redstart			Y	
Reed warbler				Y
Sedge warbler				Y
Starling			Y	
Swallow				Y
Treecreeper			Y	
Willow warbler				Y
Wood pigeon		Y		

The current study found that the presence or absence of some species was varied between sites as well as between crop types. An example of this was the reed and sedge warblers which were only found at site 'N', which is within 1 km of a

reedbed on the Eastern Cleddau river in SW Wales. Bird presence in any habitat is strongly influenced by the surrounding landscape, particularly as birds are highly mobile (Chiron *et al*. 2010) and the presence of nearby reedbed habitat could explain the presence of reed and sedge warblers at site 'N', whereas they were absent from the other sites, which were not close to reedbeds.

5.4.3 Edge effects

There appeared to be an inconsistent edge effect in *Miscanthus*, with more birds caught in the 10 m transect than the 20 m one, yet no significant differences were seen between the 10 m and 50 m transects. Although there were no significant individual species preferences for any particular transect, the distribution of birds through the crops varied widely and may account for the results recorded.

Greater species diversity has been linked to the boundaries between habitat types, and it is thought that this results from a more diverse plant assemblage and structure in such edge habitats (Yahner 1988). Higher abundance and bird species richness was reported in edge habitat of common reed *Phragmites australis* in comparison with habitats in the interior of the reedbed (Meyer *et al*. 2010). However, edge habitat may not be ideal for all species, or at all times for year; for example in a mature reedbed, reed bunting nests close to the water's edge suffered higher predation levels than those further away from the edge (Schiegg *et al*. 2007). Negative effects on reproductive success were also seen in a study on great tits in woodland habitat, whereby birds in edge habitats had lower breeding success than those in central plots. Possible reasons thought to be poorer habitat quality, higher risk of predation and overcrowding by poor quality conspecifics (Wilkin *et al*. 2007). In the present study, birds were seen flying into the *Miscanthus* crops when disturbed and its use as a refuge from predators could explain why higher numbers were caught within the first 10 m from the crop edge. However the fact that the number of birds in the 50 m transect was not significantly different from

the 10 m transect suggests that they were doing something other than evading predators and therefore were likely to have been engaged in activities related to feeding or breeding, even if this was not witnessed.

5.4.4 Sex and age

Although many of the birds caught in the breeding season were in juvenile plumage, birds less than a year old were not statistically more likely to be caught in either biomass crop than those of one year old or more. No bird nests were seen within either of the crops, but it is entirely possible that breeding was taking place, given the abundance of young birds. It is not always possible to sex birds caught in the mist nets – some species are not sexually dimorphic and for those species where a difference between the appearance of the two sexes exists, the juvenile plumage often does not show the dimorphic characteristics required. Despite this, for those birds that could be sexed, no significant bias in the sex ratio was seen in either of the crops.

5.4.5 Recaptures

The small number of recaptures within the biomass crops does not reveal a great deal about the individual's crop preference as some were recaptured in the same crop and some in the other habitat types. Time elapsing between captures ranged from weeks to months, but no between-year recaptures were found. Some birds had gained weight since first capture and others weighed less. Seasonal changes in food abundance are more likely to have been responsible for this, rather than diurnal weight changes, as trapping was carried out during the same time of day at each survey. Reasons for a low recapture rate may have been due to mist-net avoidance by wary individuals (Remsen & Good 1996), mortality or transient populations that had moved on by the next survey.

5.4.6 Feeding ecology and condition scores

All species for which a significant difference in abundance was seen between habitats were species which fed on invertebrates and either seeds or fruit/berries. Analysis was based on feeding habits throughout the year, as some granivores and their chicks feed on invertebrates during the breeding season (Bellamy *et al*. 2009). If the invertebrate feeders are indeed foraging within the crops, then it is assumed that adequate food supplies are available. For species reliant on small grass and weed seed during the winter such as the reed bunting (Peach *et al*. 1999), the relatively abundant ground cover by this type of non-crop vegetation as well as the presence of some bare earth may be important.

5.4.7 Crop management effects

Although herbicides are required for the first two years after establishment of biomass grass crops, after this time the canopy closes early enough in the growing season to prevent competitive weeds from dominating and no further herbicide should be required for the life of the crop (DEFRA 2001). Although there have recently been reports of the first potential aphid pests on *Miscanthus* crops in the USA (Bradshaw *et al.* 2010), it is not known to have any invertebrate pests in the UK at the current time and therefore does not require insecticide applications (DEFRA 2001). Although Semere & Slater (2005) reported the presence of peach aphids *Myzus persicae* in *Phalaris*, they were not deemed to be in sufficient quantities to have detrimental effects on yield. Agrochemicals, particularly pesticides are well documented as having both direct and indirect negative effects on birds (Boatman *et al*. 2004; Benton *et al*. 2002; Holland *et al*. 1999; Moreby & Southway 1999). The absence of agrochemical inputs to biomass grass crops can only be a positive influence for birds in this respect, as a higher abundance of plant and invertebrate food is likely to be present within the crops. Annual and perennial weeds were surveyed in the biomass crops and both they and their

associated invertebrates as potential food resources for birds have been discussed in Chapter 2.

The biomass crops are left standing over the winter, with harvest occurring in spring. This timing of harvesting optimises the lowering of both moisture and nutrient levels within the biomass: harvest in winter or autumn results in higher levels of pollutants such as sulphur dioxide when the material is burned (Lewandowski & Heinz 2003). This spring harvest ensures that winter habitat, capable of providing shelter and invertebrate food is available to the birds within the crop and also ensures that no bird nests are destroyed, as may happen in arable crops harvested in late summer and autumn.

5.4.8 Bird diversity

The nature and significance of variation in bird diversity in the current study very much depended on which index was used. The most basic measure, species richness, was higher in the *Miscanthus* and *Phalaris* than the comparison plots. Biodiversity is considered to be more than just the number of species present and scores such as the Shannon-Wiener Index both take into account and give extra weight to rare species and evenness of species counts. In the case of the Shannon-Wiener index, non-significant differences were apparent, whereby *Miscanthus* appeared to contain the most diverse bird assemblage. Caution must be used, however when using these indices when applied to low counts. When diversity indices were calculated per visit, a habitat with one each of two species, two each of two species or one each of four species all scored a maximum diversity count on the Simpson's index, whereas in reality they would not be considered to be diverse at all. Where only one individual of one species was recorded in a habitat, it was impossible to calculate a diversity score and therefore these data were omitted from analysis, (even though the absence of birds itself says something useful about the habitat).

There were also differences between analyses based on whether the diversity score was calculated for the habitat as a whole (i.e. total number of individuals of each species present in each habitat during all surveys) or whether diversity scores are calculated at each visit and a mean of these values is used. In order to perform statistical analysis, the latter is required, but the resulting figures are considerably different from the whole-habitat scores, particularly when calculating the Shannon-Wiener index. Even then, differences in variances in the indices make traditional statistical analysis such as ANOVA impossible (Rogers & Hsu 2001). Izsak & Papp (2000) argue that traditional ecological diversity scores and other measures of biodiversity do not adequately describe the relationship between the taxonomic differences and abundance that is necessary to truly define the biodiversity of a system. Various alternative biodiversity indices have been suggested (Campos & Isaza 2009; Benayas & de la Montana 2003), but as yet, the Simpson Index of Diversity and Shannon-Wiener index remain the best-known and most regularly used. The Simpson's Index certainly seems to be unrepresentative in the analysis of the low bird numbers per visit in this study and should be interpreted with caution in comparison with other habitats where greater numbers were recorded.

Seasonal variation in diversity scores were seen in the biomass crops, although these variations themselves varied between the diversity indices. Simpson's Index of Diversity was higher in spring, whereas Shannon-Wiener was higher in the autumn. This difference may be due to the greater weighting of rare species in the Shannon-Wiener Index, but again shows inconsistencies between the indices.

5.4.9 Species of conservation concern

This study recorded fewer red-listed birds within either of the biomass crops than the comparison plots, but other published studies of birds in *Miscanthus* have

reported differently (Sage *et al*. 2010; Bellamy *et al*. 2009; Semere & Slater 2005). Of note, three red-listed farmland birds (linnet, yellow wagtail and yellowhammer) were recorded in all three studies (Table 5.20 (a)). Two studies reported fieldfare, grey partridge and house sparrow, while corn bunting and lesser redpoll were only recorded by one (Sage *et al*. 2010; Bellamy *et al*. 2009; Semere & Slater 2005). It is possible that the other studies took place in areas dominated by arable farming and were therefore more likely to encounter these species, which are more typical of arable landscapes than the current study, which included predominantly pastoral areas.

A red-listed bird that was recorded in all three habitats in this study was the song thrush. Although there were no statistically significant differences between habitats, it was recorded more times in the *Miscanthus* than the *Phalaris* or the comparison plots.

The other red-listed species seen in *Miscanthus* in the current study was the skylark. Although this species has been recorded in other studies in *Miscanthus*, it was found in lower numbers than in comparison plots of arable, grassland or short rotation coppice (SRC) willow (Sage *et al*. 2010: Bellamy *et al*. 2009). The skylark prefers to nest in open areas, and more particularly where swards are less than 30 cm tall (Chamberlain *et al*. 1999). This has led to speculation that the closed canopy formed by mature *Miscanthus* would be unsuitable as nesting habitat and may even form a 'breeding trap' where the nests are initiated while the crop is still very short, the rapid growth of the crop leads to abandonment of nests prior to the young fledging (Anderson *et al*. 2004). Bellamy *et al*. (2009) found that areas of sparse crop growth and gaps in the canopy allowed the skylark and meadow pipit to continue using the fields even as the crop matured. This sparse canopy, however, may not be available in better-managed, dense crops of the type surveyed by Sage *et al*. (2010), which supported fewer skylark than comparison plots of wheat, grass

or SRC. Even if *Miscanthus* does provide areas suitable for nesting, it is less likely to be used for foraging during the breeding season. The skylark depends on early detection of predators, favouring open areas of field away from the hedges (Wilson *et al*. 2005) and thus may choose not to remain in *Miscanthus* fields to forage once the crop has started to grow tall. With regard to *Phalaris* as a potential skylark nesting habitat, Vepsäläinen (2010) concluded that although the crop architecture was suitable for a first nest in the breeding season, it became poor habitat for any subsequent broods. In May, he reported that *Phalaris* contained equivalent skylark numbers to the comparison conventional crops, but by June their numbers were lower in *Phalaris* and by July they were only seen near the edge of the crop rather than in the middle.

A large number of amber-listed birds were recorded in the biomass crops. One of these recorded at three sites was the reed bunting, which was recorded in both biomass grass crop types, although its abundance was non-significantly higher in the *Phalaris*. It has been one of the species particularly affected by agricultural intensification, with a 59% reduction in population across the whole of the UK between 1968 and 1991 (Fuller *et al*. 1995). Peach *et al*. (1999) attribute the advent of widespread herbicide use to its decline, through the resulting reduced availability of small grass and weed seeds on which they rely for over-winter survival. The reed bunting was red-listed from 1996 to 2007 but was then down-graded to amber as populations had stabilised at reduced levels (www.BTO.org).

Brickle & Peach (2004) found that rank and emergent vegetation was preferred by reed buntings in comparison with set-aside, oil-seed rape and cereals. This was thought to be due to the superior foraging opportunities and also concealment of their nests in this habitat. This was in agreement with the findings of Siriwardena *et al*. (2001), whereby breeding success of the reed bunting was negatively associated with increasing areas of arable land. Reed buntings were recorded in the

three previously mentioned studies on birds in *Miscanthus*, so the biomass grass crop habitat is apparently very suitable for them. Bradbury *et al.* (2010) reported on agri-environment prescriptions likely to benefit farmland birds as well as enhancing ecosystem service delivery. They suggested that the planting of small-scale wetlands around field margins as buffer zones for pollutants increased invertebrate diversity and provided habitat for reed buntings, sedge warbler and grasshopper warbler. The introduction of biomass grass crops into arable areas would also create suitable habitat for reed bunting, whilst still being a commercially viable crop.

Birds were not systematically surveyed in the uncultivated field margins. Due to the narrow nature of the margins (2 – 6 m), it would have been impossible to tell whether any birds caught in mist nets within them were utilising the margins, or simply moving between the hedge and crop. However, the presence of rough, grassy, uncultivated margins of 6 m width around the biomass crops is likely to benefit many different bird species. The barn owl relies on this habitat for hunting small mammals, but the reduced availability of rough grassland of this kind and hay meadows on farmland in recent times is associated with a negative impact on the barn owl (Bond *et al.* 2005). It has also been shown that an optimal width of grass strip for hunting barn owls is 7 m (Askew *et al.* 2007) and as such, the 6 m margins present around the biomass crops may be valuable. Uncultivated and unsprayed field margins also tend to have high botanical diversity (de Snoo 1999) which in turn can attract a higher diversity of invertebrates. A similar botanical composition would have been found on set-aside land, which was reported to increase the density and diversity of bird species when compared to tillage or grass (Gillings *et al.* 2010; Bracken & Bolger 2006). As compulsory set-aside has now been discontinued, many farmland bird species will have suffered reduced habitat availability as a consequence (Gillings *et al.* 2010), and the presence of uncultivated

field margins such as those around the biomass crops may become ever more important.

5.4.10 Habitat associations and groupings

Most of the birds recorded within the biomass crops in this study were considered to be predominantly woodland species, as had also been reported by Sage *et al*. (2010) and Bellamy *et al*. (2009). Nonetheless, it was unexpected that the goldcrest, usually associated with conifers (www.BTO.org) should be found in *Miscanthus* at two different sites.

Species normally associated with open ground were recorded within the crops, but only at a time when the crop was newly harvested or in the very early stages of growth, which is in agreement with the findings of Bellamy *et al*. (2009). The heterogeneous structure of *Miscanthus* throughout the year in addition to the presence of wide uncultivated margins and hedgerows around it provide potential nesting and foraging habitat for a wide variety of birds.

In terms of habitat structure, the closest approximation to *Miscanthus* would be a reedbed, and it is therefore not unexpected that sedge and reed warbler and waders were present within it. Although this study found species such as the reed warbler and sedge warbler (usually associated with reedbeds) in the *Phalaris*, it is unknown what influence the close proximity of the *Miscanthus* may have had. At the three sites where *Phalaris* was grown, there was a *Miscanthus* plot within 10 m of it. The architecture of the *Miscanthus* may have been more suitable for nest-building by these warblers, and the adjacent *Phalaris* may just have been used for foraging. Vepsäläinen (2010) studied *Phalaris* crops in Finland and recorded grasshopper warbler *Locustella naevia* and Blyth's reed warbler *Acrocephalus dumetorum* within the *Phalaris*, but not within cereal comparison plots, suggesting that the

Phalaris is indeed a good warbler habitat, even in the absence of adjacent *Miscanthus*.

Several of the taxonomic groups of birds in this study (dunnocks/wrens, finches/buntings, tits/warblers) were only found within the biomass crops, reflecting the fact that these groups predominantly represent birds of woodland or reedbed rather than open farmland. The groups containing corvids, pheasants/pigeons and thrushes/starlings were found in non-significantly higher abundance in the comparison plots than the biomass crops. Again, variance in abundance was high, particularly for the thrushes/starlings, whose high numbers were predominantly composed of flocks of redwings and starlings.

5.4.11 Seasonal changes

All three habitats contained non-significantly higher species numbers and abundance of birds in the summer / breeding season in comparison with winter. This was partially influenced by the influx of some summer migrants, but it is not known whether this is because the crops were being utilised for breeding, feeding or shelter by the birds present. Semere & Slater (2005) reported the crops being used for breeding by the skylark, grey partridge, lapwing and pheasant, whilst pheasant, grey partridge, wren and linnet were seen foraging in the crops during the winter. Bellamy *et al*. (2009) recorded breeding pairs of pheasant, skylark, red-legged partridge, reed bunting and reed warbler in the *Miscanthus*. In Japan where *Miscanthus* is a native plant species, Stewart *et al*. (2009) reported the eastern great reed warbler *Acrocephalus arundinaceus orientalis*, Japanese reed bunting *Emberiza yessoensis* and meadow bunting *Emberiza cioides* nesting in *Miscanthus sinensis*, one of the parent forms of the hybrid *M.* x *giganteus*. Further work on how birds move around and utilise the crops through the use of radio-telemetry, or by direct observations of behaviour, would be most useful for understanding the spatial and temporal patterns of habitat use in biomass crops.

5.4.12 Biomass grass crops in the context of effects of agricultural intensification

Birds in western, grassland dominated areas of the UK have declined more markedly than in other parts of the country (Chamberlain & Fuller 2001; Gates & Donald 2000). The cultivation of biomass grasses may provide additional habitat for declining bird species – either through the structure and resources within the crop, or from the associated uncultivated field margins. The presence of these margins within arable areas may, in some way compensate for the loss of set-aside land, by providing floristically diverse areas of vegetation.

Herbicides are known to have both direct and indirect effects on granivorous and insectivorous birds (Buckingham *et al.* 2006; Boatman *et al.* 2004; Moreby & Southway 1999) and a habitat free of these chemicals is likely to have positive impacts on these birds. Although herbicides may used in the first two years after establishment of the biomass grass crops, usually there is no further requirement for agrochemicals, potentially for 20 years in *Miscanthus* and five years in *Phalaris*, if the crops are grown to their maximum life-span. In *Miscanthus*, the architecture of the rhizome clumps and occasional gaps in between the plants allow some weeds to grow. However, these weed patches tend not to be very dense or tall and therefore make good foraging patches for granivorous birds feeding on their seeds. Although the stems of *Phalaris* tend to grow more densely together, some weeds also grow within the crop, attracting pollinating and herbivorous insects (see Chapter 2) as well as providing a seed resource. Intrinsically, *Phalaris* is likely to be a good food resource for granivorous bird species as it produces large seed-bearing heads.

Many over-wintering granivorous birds feed on the small grass and weed seeds that have grown within stubbles that have been left over the winter prior to sowing of spring crops (Fuller *et al.* 1995). Where stubbles are sprayed with herbicide and ploughed in autumn prior to the planting of winter cereals, no such weed cover exists. The weeds present within the biomass crops may be an important foraging

resource. In addition, the dry standing biomass provides an architecturally distinct habitat providing shelter during the winter, unlike other arable crops, which are harvested in the autumn.

5.4.13 Conclusions

A diverse range of birds was recorded in both biomass grass crops, although *Miscanthus* contained a higher abundance and diversity than the *Phalaris*. Birds recorded within the biomass crops tended to be of species usually associated with woodland or reedbeds rather than farmland specialists, although some of these were also present in lower numbers. A combination of mist-netting and walking surveys revealed a greater number of species than either technique alone. No differences in sex, age or body mass were seen in birds captured in either crop.

Although the overall impact of biomass grass crops on different bird species varies, the evidence presented in this chapter provides support for the view that the crops create new structural habitat that provides food resources and shelter for birds on farmland in comparison with areas of grazed pasture.

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CHAPTER 6

GENERAL DISCUSSION

6.1 The challenge of quantifying biodiversity

The remit of this thesis was to examine the biodiversity of birds, small mammals, invertebrates and non-crop plants within plantations of *Miscanthus* and *Phalaris* biomass crops, and to compare this with the biodiversity of adjacent areas of farmland. It is assumed that these biomass crops would primarily be grown commercially as feedstock for biomass energy but with other potential uses for the end product such as animal bedding, paper or thatching.

The first issue that arose with the remit was that of how best to measure biodiversity. In this thesis, a wide range of survey techniques targeting many different taxonomic groups was used, as it was felt that a novel crop such as *Miscanthus* warranted a broad approach. It has been suggested that surrogate measures of biodiversity using narrow taxonomic groups are appropriate under certain circumstances (e.g. Anderson *et al*. 2011; Bohac 1999; Kevan 1999). Such a narrow approach can require high levels of taxonomic expertise to identify an invertebrate genus such as Carabidae (Coleoptera) to species level, yet still relies on the assumption that the diversity represented by the focal taxon is representative of biodiversity across all taxa, which is not necessarily valid. Indeed, the results of the present study suggest that for these biomass crops, using a narrow taxonomic group as a measure of overall biodiversity may be inappropriate. Three measures of biodiversity were examined: species (or family) richness, Simpson's index and Shannon's index, but for each major taxonomic group considered (birds, small mammals and invertebrates), a different habitat was deemed to be the best for maximising biodiversity. Small mammals, as defined by the three measures were more diverse in *Phalaris*, but birds were most diverse in *Miscanthus*. Invertebrates were most diverse in the headlands as defined by family richness and the Shannon-Wiener index, but were most diverse in *Miscanthus* in terms of the Simpson's index. These differences highlight the fact that the apparent value of a habitat for

biodiversity depends dramatically on the measures of biodiversity and the taxonomic group(s) used.

Even the calculation of the diversity indices provided different results, depending on exactly how they were calculated; either using the total number of individual species/families recorded per habitat across the year, or using the mean of the index-specific score calculated at each visit.

When either biodiversity index has been calculated, unequal variances exist, even if the groups being compared are of an equivalent size (Rogers & Hsu 2001) and therefore parametric statistical tests such as ANOVA are not appropriate. Alternative measures of diversity that can be more readily tested for statistically significant differences have been proposed (Rogers & Hsu 2001), but these are not as well recognised nor as easily calculated as either Simpson's or Shannon's indices.

6.2 Limitations of methods used.

Many of the survey techniques used were very dependent on fair weather conditions, which did not always prevail. This resulted in varying time spans between surveys at the same sites. Sometimes it took nearly the whole two month sampling interval for appropriate weather conditions to allow the completion of surveys at all four study sites, which meant that in the peak of the growing season, crop height was much taller at the last of the sites to be surveyed in the two-month period than it was at the first site. Thus, interpretation of seasonal effects may also have been influenced by crop height / time within the sampling interval as well as by the time of year.

The rapid growth rate of the *Miscanthus* and resulting dense stems made movements through the crop very difficult. This did not directly affect bird and

small mammal trapping techniques, but certainly had an effect on invertebrate sampling using a sweep net.

In this study, it was considered that the use of mist nets to capture birds in the headlands was inappropriate, as it would be impossible to determine whether the bird was moving between the crop and the hedge, or actively using the headland. Other authors who surveyed birds in *Miscanthus* (e.g. Sage *et al*. 2010 and Bellamy *et* al. 2009) reported using a technique, whereby an observer counted all birds flushed up out of the crop by someone else walking through the crop. In the early phases of *Miscanthus* growth, this may be a good technique to use, but as the crop reaches head-height and above, it became more difficult to see any birds flying out of the crop.

6.3 Benefits to biodiversity

Overall, crop fields of *Miscanthus* and *Phalaris* contained a higher diversity of birds and small mammals than the comparison sites. The hedgerows and headlands were the best habitat for small mammals in terms of abundance, and for invertebrates in terms of diversity. Providing that plantations of these biomass grass crops retain the traditional field structure of hedgerow and headlands around the crop itself, then the quantity of available good habitat to all taxa will be maintained.

6.4 Red-listed and Biodiversity Action Plan (BAP) species

The harvest mouse was the notable small mammal BAP priority species found within the biomass grasses at one site, and this study provided the first record of their presence in that local area. Previous records in the whole county (Pembrokeshire) only numbered 3 in the last 10 years and 7 prior to 2000, with the closest previous record more than 10 km away.

The current conservation status of the water shrew is unclear. Despite usually being associated with fast-running streams, and occasionally being found in woodland or other habitats, it was recorded in the biomass crops at three sites. One site contained particularly high numbers, all of which were captured during winter months. Either this type of agricultural habitat is commonly used by water shrews, but they have been under-recorded in previous studies, or the biomass crops may provide a particularly suitable winter habitat for the water shrew.

Although the biomass crops contained some red-listed bird species, they were more prevalent in the comparison sites. This may reflect the fact that many of the red-listed birds found on agricultural land are farmland specialists, requiring specific habitat such as open areas of short grass sward (e.g. starling) or regularly tilled and cropped land (skylark). Although the biomass grasses did not necessarily provide optimal habitat for these declining farmland specialist birds, they did create habitat that was well used by other bird species.

6.5 Winter shelter

A key feature of the biomass grass crops is the fact that they are left standing over the winter. Although leaving the crop to stand in-situ until spring harvest is known to slightly reduce overall biomass, the quality of the resulting combusted material is improved by harvest in spring rather than autumn. This management practice provides valuable winter habitat that is not available where any other commercial grass or cereal crop is grown in the UK. The biomass crops may act as surrogates for reedbed habitat for flock-roosting winter bird species and also appear to support a high winter abundance of small mammals. This benefit to small mammals was demonstrated at the ADAS experimental plot at site 'PP' in Ceredigion, where there was a significantly higher small mammal abundance during the winter months in the *Phalaris* crop that was left standing at full height

until February, in comparison with areas of the crop that were mown in August (leaving only very short crop re-growth over the winter).

6.6 Trophic relationships and food availability within the crops

It could have been tempting in this thesis, to try to correlate abundance and diversity of invertebrates and weeds with the birds and small mammals present and then to infer possible trophic relationships. However, such statistical associations do not necessarily imply cause and effect. Rather, this thesis has shown that plant and invertebrate food resources known to be important for birds and small mammals were recorded within the crops and that therefore the biomass grass crops are likely to be good habitat for them.

Future work could include the use of radio-telemetry to track the small-scale movements of both resident birds and small mammals, in order to determine how they are using the biomass crops. It would be useful to determine whether shelter is the key benefit within the crops, or whether sufficient food resources exist within them for the animals to remain there without dependence on other available habitats.

6.7 Ecosystem services

Within the existing biomass grass crop field structure that included a hedgerow and uncultivated wide headland, many beneficial invertebrates including pollinators, parasitoids and predators were found. As a native species in the UK, *Phalaris* may naturally suffer attacks by pests, but it is not known whether this is at economically damaging levels. At the current time, *Miscanthus* in the UK, as a non-native species, does not have any known insect pests, and there is no requirement for insecticide use in the crops. This absence of insecticide use could mean that the biomass grass crops can act as a reservoir of beneficial invertebrates able to perform biological control of pest species in adjacent arable crops through predation or

parasitism. The uncultivated margins and weedy patches within the crops also provided nectar sources for both pollinators and parasitoids. In an otherwise homogenous monoculture landscape, these field margins and non-crop plants could be essential in maintaining a high diversity of these invertebrates in agricultural landscapes.

Many invertebrate families found within the crops are essential for breaking down organic matter and returning carbon to the soil. Both *Miscanthus* and *Phalaris* fields are reported to be net sinks of carbon (Shurpali *et al*. 2009; Kahle *et al*. 2001) and as such have a potentially important role in contributing to reducing atmospheric CO_2. As biomass crop species are perennial plants, tillage is dramatically reduced in comparison with annual crops such as the main food crops, further reducing organic carbon losses from the soil. Furthermore, the use of biomass grasses as a renewable fuel (in that growth of the crop removes the same amount of carbon from the atmosphere as its combustion releases) reduces the need for fossil fuels to be combusted. If the biomass grass crop fields are only a short distance from the power station, then transport costs are low and the net carbon costs of producing biomass fuel are low, such that the biomass crops can be a very low-carbon energy source (Department for the Environment, Food and Rural Affairs (DEFRA) 2007).

6.8 Opportunities for future work

The current study included surveys in two commercial crops and two experimental plots of biomass grasses, which resulted in a range of plot sizes being available. Further work on larger commercial crops that includes surveys further than 50 m into the crop from the crop edge would be necessary in order to assess the impact of cropped areas of a larger size.

The use of radio-telemetry for small mammals and birds using the biomass grass habitat would reveal more about how the crops are utilised, in terms of feeding, breeding or shelter than can be determined using the techniques described in this thesis.

6.9 Conclusions

In conclusion: plantations of biomass grass crops such as *Miscanthus* x *giganteus* and *Phalaris arundinacea* in the UK enhance the biodiversity of birds and small mammals in the agricultural landscape, when grown in small to medium sized plots surrounded by uncultivated headlands and hedgerows. Furthermore, these crop field structures also support a diversity of non-crop vegetation and invertebrates with important roles in trophic webs and the provision of ecosystem services.

6.10 References

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APPENDIX 1

Details of small mammals caught per 100 trap nights per transect in Year 1 and Year 2 (based on the first night of trapping only). Key to species: WM = wood mouse, YNM = yellow-necked mouse, HM = harvest mouse, BV = bank vole, FV = field vole, CS = common shrew, PS = pygmy shrew, WS = water shrew. Key to sites: HM = Hinton Manor, LL = Llysdinam, N = Narberth, PP1 = Pwllpeiran field 1, PP2 = Pwllpeiran field 2.

Year 1

Site	Habitat	Transect	WM	YNM	HM	BV	FV	CS	PS	WS
HM	Comparison		3	0	0	0	3	0	0	0
HM	Headland		0	3	0	0	0	0	0	0
HM	Miscanthus	10	5	3	0	0	0	0	0	0
HM	Miscanthus	20	5	0	0	0	0	0	0	0
HM	Miscanthus	50	13	3	0	0	0	0	0	0
LL	Comparison		0	0	0	0	0	0	0	0
LL	Headland		10	5	0	1	2	0	0	0
LL	Miscanthus	10	13	2	0	0	0	3	0	0
LL	Miscanthus	20	23	2	0	0	2	2	0	0
LL	Phalaris	10	12	2	0	0	0	2	0	0
LL	Phalaris	20	5	0	0	0	2	5	2	0
N	Comparison		0	0	0	0	8	2	0	0
N	Headland		2	0	0	3	0	0	0	0
N	Miscanthus	10	16	0	0	0	2	0	0	0
N	Miscanthus	20	16	0	0	0	0	0	0	0
N	Miscanthus	50	12	0	4	0	0	0	0	0
N	Phalaris	10	8	0	4	2	2	0	0	0
N	Phalaris	20	2	0	4	2	2	0	0	0
N	Phalaris	50	4	0	4	0	0	4	0	0
PP1	Comparison		0	0	0	0	0	0	0	0
PP1	Headland		8	0	0	0	0	0	0	0
PP1	Miscanthus	10	25	0	0	0	3	2	0	0
PP1	Miscanthus	20	17	0	0	3	0	0	0	0
PP1	Phalaris	10	2	0	0	0	17	2	0	2
PP1	Phalaris	20	2	0	0	2	13	0	0	0
PP2	Headland		2	0	0	0	0	0	0	0
PP2	Phalaris	10	15	0	0	0	0	0	0	0
PP2	Phalaris	20	10	0	0	0	0	0	0	0
PP2	Phalaris	50	8	0	0	0	2	0	0	0

Year 2

Site	Habitat	Transect	WM	YNM	HM	BV	FV	CS	PS	WS
N	Hedge	East	60	0	0	37	4	28	2	1
N	Hedge	South	93	0	0	55	1	3	2	2
N	Hedge	West	82	0	0	75	0	2	1	0
N	Hedge	North	31	0	0	34	14	48	10	3
N	Phalaris	20	15	0	27	4	0	14	1	5
N	Phalaris	100	32	0	19	6	4	8	1	7
N	Phalaris	180	33	0	12	1	1	15	0	2
N	Miscanthus1	20	45	0	4	8	0	2	1	1
N	Miscanthus1	100	58	0	4	6	0	1	1	2
N	Miscanthus1	180	65	0	1	14	0	3	3	3
N	Miscanthus2	20	43	0	3	1	1	6	1	0
N	Miscanthus2	180	43	0	0	5	1	13	0	5
N	Miscanthus2	180	48	0	0	11	0	8	3	2

APPENDIX 2

Birds recorded in this study, where recorded, conservation status and usual habitat associations. Conservation status from www.BTO.org, habitat associations from DEFRA 2009 (see section 5.5 for full citations). Key to where recorded: M = *Miscanthus*, P = *Phalaris,* C = comparison plots.
Key to habitat associations: F = farmland, FS = farmland specialist, LW = lowland wetland, O = other / unclassified, S = seabird, U = upland, W = woodland, WS = woodland specialist.

Family	Species	Common name	Where recorded			Status	Habitat
			M	P	C		
Aegithalidae	*Aegithalos caudatus*	Long tailed tit		1		Green	W
Alaudidae	*Alauda arvensis*	Skylark	1			Red	FS
Certhidae	*Certhia familiaris*	Treecreeper		1		Green	WS
Charadriidae	*Vanellus vanellus*	Lapwing			5	Red	FS
Columbidae	*Columba palumbus*	Woodpigeon			4	Green	F
Corvidae	*Corvus corone*	Carrion crow	1		4	Green	O
	Corvus monedula	Jackdaw			14	Green	FS
	Pica pica	Magpie		1		Green	O
Emberizidae	*Emberiza schoeniclus*	Reed bunting	6	17	2	Amber	F
Fringillidae	*Fringilla coelebs*	Chaffinch	1	1		Green	W
	Pyrrhula pyrrhula	Bullfinch	1			Amber	W
Hirundinidae	*Hirundo rustica*	Barn swallow	11	9	5	Amber	O
Laridae	*Larus marinus*	Great black backed gull			2	Amber	S
Motacillidae	*Anthus pratensis*	Meadow pipit	1	1	2	Amber	U
	Motacilla alba	Pied wagtail			1	Green	O
Paridae	*Cyanistes caeruleus*	Blue tit	18	12		Green	W
	Parus major	Great tit	6	3		Green	WS
Phasianidae	*Phasianus colchicus*	Pheasant	8	106		None	
Prunellidae	*Prunella modularis*	Dunnock	8	2		Green	W
Scolopacidae	*Numenius arquata*	Curlew	1			Amber	U
	Scolopax rusticola	Woodcock	2			Amber	SW
Strigidae	*Athene noctua*	Little owl	1			None	F
Sturnidae	*Sturnus vulgaris*	Starling		1	20	Red	FS
Sylviidae	*Phylloscopus collybita*	Chiffchaff	4	1		Green	WS
	Regulus regulus	Goldcrest	2			Green	WS
	Acrocephalus scirpaceus	Reed warbler	2	1		Green	LW
	Acrocephalus schoenobaenus	Sedge warbler	1	5		Green	LW
	Phylloscopus trochilus	Willow warbler		1		Amber	WS
Troglodytidae	*Troglodytes troglodytes*	Wren	6	11		Green	W
Turdidae	*Turdus merula*	Blackbird	21	7	7	Green	W
	Phoenicurus phoenicurus	Restart	1	1		Amber	WS
	Turdus iliacus	Redwing			10	Red	?F
	Oenanthe oenanthe	Wheatear	2			Amber	U
	Erithacus rubecula	Robin	19	4	2	Green	W
	Turdus philomelos	Song thrush	7	5	4	Red	W
	Turdus viscivorus	Mistle thrush	2		1	Amber	O
Tytonidae	*Tyto alba*	Barn owl	1			Amber	?F